DEVELOPMENT OF ENERGY-EFFICIENT BUILDING ENVIRONMENTAL QUALITY EVALUATION FRAMEWORK

NG BAN HUAT

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Assoc. Prof. Dr. HJ. ZAINAL ABIDIN B. HJ. AKASAH
Head
Department of Civil Engineering Technology
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor Darul Ta'zim
MALAYSIA

Permanent address:

JA 5279, KG. BARU SELANDAR,

77500, MELAKA.

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Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

Examiners:

PROF. MADYA DR. HJ. LOKMAN HAKIM BIN ISMAIL
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

PROF. DR. CHRISTOPHER NIGEL PREECE
Razak School of Engineering and Advanced Technology
Universiti Teknologi Malaysia

I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledge

Student :

NG BAN HUAT

Date : 09th DECEMBER 2013

Assoc. Prof. Dr. HJ. ZAINAL ABIDIN B. HJ. AKASAH
Head
Department of Civil Engineering Technology
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor Darul Ta'zim
MALAYSIA

Supervisor :

ASSOCIATE PROFESSOR DR. HJ. ZAINAL ABIDIN BIN AKASAH

Dedicated to my beloved parents, sister, brother and all my friends

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ABSTRACT

This research is about the development of an energy-efficient building environmental quality evaluation framework for office building in hot and humid climatic regions. The aim of this research is to develop an evaluation framework for the identification of problems with respect to energy-efficient design affecting occupants' comfort. This research focuses on the application of energy-efficient design in office building; secondly, identifies the effects of energy-efficient design problems towards occupants' comfort; and finally proposes an evaluation framework for the rating of energy-efficient design problems which affect the occupants' comfort. This research was conducted at three energy-efficient buildings in Malaysia. A new building performance evaluation framework Energy-efficient Building Environmental Quality Evaluation Framework has been constructed and tested at the selected energy-efficient buildings. The tested results were then analyzed using Statistical Package for Social Science (SPSS) in order to determine its reliability and validity. The research outcomes have shown high reliability and validity of the validated newly designed evaluation framework. In conclusion, this research has shown that the newly designed Energy-efficient Building Environmental Quality Evaluation Framework is able to identify the occupants' comfort level in energy-efficient building and the causes of the problems which is mainly due to the building envelop such as shading and window features of the energy-efficient building.

ABSTRAK

Kajian ini adalah mengenai pembangunan rangka kerja penilaian kualiti persekitaran bangunan bagi bangunan pejabat yang terletak di kawasan beriklim khatulistiwa, kajian ini bertujuan untuk membangunkan satu rangka kerja penilaian bagi mengenal pasti masalah-masalah reka bentuk cekap tenaga yang mempengaruhi keselesaan penghuni. Kajian ini bertumpu pada aplikasi reka bentuk cekap tenaga dalam bangunan pejabat, kedua, mengenal pasti kesan daripada masalah-masalah reka bentuk cekap tenaga yang mempengaruhi keselesaan penghuni dan akhir sekali, mencadangkan rangka kerja penilaian bagi mengenal pasti masalah reka bentuk cekap tenaga yang mempengaruhi keselesaan penghuni. Kajian ini dijalankan di bangunan cekap tenaga yang terdapat di Malaysia. Satu rangka kerja penilaian prestasi bangunan yang baru, Rangka Kerja Penilaian Kualiti Persekitaran Bangunan telah dirangka dan diuji di bangunan-bangunan cekap tenaga yang terpilih. Keputusan pengujian dianalisis dengan menggunakan perisian pakej statistik untuk sains sosial atau *Statistical Package for Social Science* (SPSS) bagi menentukan kebolehpercayaan dan kesahannya. Hasil dapatan kajian menunjukkan Rangka Kerja Penilaian Kualiti Persekitaran Bangunan mempunyai kebolehpercayaan dan kesahan yang tinggi. Kesimpulannya, kajian ini telah menunjukkan Rangka Kerja Penilaian Kualiti Persekitaran Bangunan ini mampu mengenal pasti tahap keselesaan penghuni di bangunan cekap tenaga dan punca pada masalah keselesaan penghuni adalah disebabkan kedudukan tingkap and pengadang yang digunakan di bangunan cekap tenaga yang dikaji.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percents
CO_2	-	Carbon Dioxide
CVR	-	Content Validity Ratio
hrs/wk	-	Hours per week
kW	-	Kilowatt
kWh	-	Kilowatt-hour
kWh/m^2	-	Kilowatt hours per meter square
kWh/m^2/yr	-	Kilowatt hours per square meter per year
kWh/year	-	Kilowatt hours per year
m	-	Meter
m^2	-	Square meter
MJ	-	Mega joule
mm	-	Millimeter
n/2	-	number of panelists divided by two
n_e	-	number of panelists indicating “essential”
r	-	rho
Tvis	-	*Visible Transmittance*
α	-	Alpha
AHU	-	Air Handling Unit
AIA	-	American Institute of Architects
APEC	-	Asia-Pacific Economic Cooperation
ASEAN	-	Association of Southeast Asian Nations
ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
BASE	-	Building Assessment Survey and Evaluation
BEI	-	Building Energy Index

BIPV	-	Building Integrated Photovoltaic
BIU	-	Building-In-Use
BQA	-	Building Quality Assessment
BREEAM	-	BRE Environmental Assessment Method
BS5240	-	Industrial Safety Helmets - specification for construction and Performance
BUS	-	Building Use Studies
CBE	-	Center for the Built Environment
CDC	-	Centers for Disease Control and Prevention
CFL	-	Compact Fluorescent Lamp
CMC	-	Chilled Metal Ceiling
COPE	-	Cost effective Open Plan
CPEC	-	Car park Energy Consumption
CRT	-	Cathode Ray Tube
CVI	-	Content Validity Index
DCA	-	Data Centre Area
DCEC	-	Data Centre Energy Consumption
DDC	-	Direct Digital Control
DTU	-	Danmarks Tekniske Universitet
EEBEQ	-	Energy-efficient Building Environmental Evaluation Framework
EDPM	-	Electronic Data Processing Machine
EEMP	-	Energy Efficiency Master Plan, Malaysia
EMS	-	Energy Management System
ERV	-	Energy Recovery Ventilation
ETP	-	Engineering Thermoplastic
FVR	-	Weighted Floor Vacancy Rate
GBI	-	Green Building Index
GEF	-	Global Environment Facility
GEO	-	Green Energy Office
GFA	-	Gross Floor Area
GLA	-	Gross Lettable Area
HFSQ	-	Human Factors Satisfaction Questionnaire

HOPE	-	European Health Optimization Protocol for Energy-efficient buildings
HVAC	-	Heating, Ventilating, and Air Conditioning
IAQ	-	Indoor Air Quality
ICC	-	Intra-class Correlation Coefficient
ICIEE	-	International Center for Indoor Environment and Energy
IEQ	-	Indoor Environmental Quality
KeTTHA	-	Ministry of Energy, Green Technology and Water, Malaysia
KKR2	-	Kompleks Kerja Raya 2
KL	-	Kuala Lumpur
KLCC	-	Kuala Lumpur City Center
LCD	-	Liquid Crystal Display
LED	-	Light-Emitting Diode
LEED	-	Leadership in Energy and Environmental Design
LEO	-	Low Energy Building
MIEEIP	-	Malaysia Industrial Energy Efficiency Improvement Project
MIT	-	Massachusetts Institute of Technology
MPS	-	Mapping previous study
MS 1525:2001	-	Code of Practice on Energy Efficiency and use of Renewable Energy for Non-residential Buildings
PC	-	Personal Computer
PCM	-	Phase Change Material
PEX	-	Cross-linked polyethylene
POE	-	Post Occupancy Evaluation
PROBE	-	Post-occupancy Review of Buildings and their Engineering
PV	-	Photovoltaic
REF	-	Ratings of Environmental Features
RIBA	-	Royal Institute of British Architects
RSF	-	Research Support Facilities
SBS	-	Sick Building Syndrome

SC	-	Shading Coefficient
SCATS	-	Smart Controls and Thermal Comfort
SHGC	-	Solar Heat Gain Coefficient
SPSS	-	Statistical Package for the Social Sciences
SRI	-	Solar Reflectance Index
SSSH	-	Self-Sufficient Solar House
TBEC	-	Total Building Energy Consumption
TBP	-	Total Building Performance
UBBL	-	Uniform Building By-Laws, Malaysia
UCB	-	University of California, Berkeley
UK	-	United Kingdom
UNDP	-	United Nations Development Program
UNEP	-	United Nation Environment Program
USA	-	United States of America
VAV	-	Variable Air Volume
VFD	-	Variable-Frequency Drive
VOCs	-	Volatile Organic Compounds
VSD	-	Variable-Speed Drive
VT	-	Visible Transmittance
WHO	-	Weighted Weekly Operating Hours
ZEB	-	Zero Energy Building
ZEH	-	Zero Energy Home

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CHAPTER 1

INTRODUCTION

1.1 Background of research

This research is about the development of an energy-efficient building environmental quality evaluation framework for office building in hot and humid climatic regions. According to the National Institute of Building Sciences (2008), human comfort is one of the important aspects needed to be taken into account while developing an energy-efficient building. Therefore, the development of energy-efficient building environmental quality evaluation framework involves identifying the occupants' comfort level in energy-efficient building through its assessment criteria such as thermal comfort, lighting, acoustics and indoor air quality (IAQ). Such effort could help to prevent repeating past mistakes particularly from the aspect of occupant's comfort in the future development of energy-efficient building.

In this study, the term "energy-efficient building" is used as a collective term for different types of buildings made to reduce energy consumption; and the aim of these buildings is to cope with the problems derived from the over consumption of natural resources mostly coal, which is used by building during its operational process. At present, there are three office buildings specifically designed with energy-efficient features in Malaysia, (1) Ministry of Energy, Communications, and Multimedia office building or well known as Low Energy Office (LEO); (2), Green Energy Office (GEO) which housed the office building for Malaysia Green Technology Corporations; and (3), Energy Commission office building or known as ST Diamond.

These buildings are the initiatives demonstrated by the government to fully engage in the sustainable development (United Nations Environment Programme, 2011).

1.2 Problem statement

The development of a sustainable building rating system such as Leadership in Energy and Environmental Design (LEED), and Malaysian Green Building Index (GBI) reflected the current focus of the building performance objectives mostly on *optimizing energy and resource efficiently*. Although the current focus on building energy performance is high yet some of the buildings particularly energy-efficient buildings are still not able to achieve the low energy consumption in terms of the yearly energy use. Newsham *et al*. (2009) analyzed the data supplied by the New Buildings Institute and the US Green Buildings Council on measured energy use data from 100 LEED-certified commercial and institutional buildings and had found that 28–35% of LEED buildings use more energy than their conventional counterparts. A study by the New Building Institute (2008), also found about 30% of LEED rated buildings perform better than expected, 25% perform worse than expected and a handful of LEED buildings have serious energy consumption problems. These problems are due to repetition of past mistakes by creating unnecessary and wasteful complexity, which can undermine the green buildings' whole purpose (Leaman & Bordass, 2007).

The inefficiency of the current energy-efficient buildings' performance might be caused by the overlook of the importance of buildings' Indoor Environmental Quality (IEQ). According to Department of Energy (2001), in the development of energy efficiency program for building, it is important to appreciate that the fundamental purpose of the building is to serve occupants and their activities rather than to save nor use energy. The above statement was further supported by Heerwagen & Zagreus (2005). From the research they had conducted, they found out that sustainable building design strategies are able to create improved indoor environmental quality (IEQ) and should thus be associated with improved occupants' comfort, satisfaction, health, and work performance relative to buildings designed around standard practices. The improvement of work performance could also serve as a strong stimulus for energy conservation measures that simultaneously improve indoor environments (Fisk, 2000). The importance of building's IEQ especially in energy-efficient buildings has led to the development of Health Optimization Protocol for Energy-efficient Buildings (HOPE) project, a research funded by European Union countries that aims to create healthy and energy-efficient buildings in the region (Bluyssen & Loomans, 2003).

A research done by Baird *et al.* (2011) shows that the perception of the user towards "sustainable building are better than the "conventional building" in terms of IEQ aspects such as lighting, noise, temperature and air quality. In another study, users have high degree of satisfaction toward overall performance of energy-efficient building (Zainordin, Abdullah & Ahmad, 2012). A research carried out by Ismail & Sibley (2006) show that bioclimatic high rise office building creates a better working environment for the users and provides higher level of satisfaction than conventional ones. The passive design strategies that apply in energy-efficient building in Malaysia on the average, proven effective at improving indoor thermal comfort, which in turn lead to improving occupant satisfaction. Besides high level of users' satisfaction towards energy-efficient buildings, empirical result also show indoor thermal and ventilation condition in bioclimatic buildings are better than that of conventional ones (Ismail, Sibley & Wahab, 2011).

Evidence from recent post-occupancy evaluations done by Abbaszadeh *et al.*, (2006) also found potential for green building to enhance the IEQ. However, they often fall short. Their research found that although some of the best green buildings can rank higher than the best conventional buildings in terms of occupants experience towards comfort, health and productivity, a few of the lowest scoring buildings on user experience are also reported as green building or energy-efficient building. According to Wall (2006), many buildings, once in operation, are not as energy-efficient and thermally comfortable as expected. Research on comparing the comfort level of green buildings and conventional buildings conducted by Paul & Taylor, (2007) concluded that, there was insufficient evidence to support that green buildings are more comfortable than conventional buildings, particularly, with respect to aesthetics, serenity, lighting, ventilation, acoustics, and humidity. A similar outcome from the research carried out by Hinge *et al.* (2008) also shows that some of the energy-efficient buildings actual performance is quite different from their predicted performance, especially for the first year. A research carried out by

Qahtan *et al.* (2010) in two energy-efficient buildings in Malaysia show occupants have less satisfaction on the air movement of the building which could be improved through mechanical ventilation.

Different reasons have been suggested in the literature, which include lack of feedback across the building life cycle (Kalay, 2006); and in terms of more technical issues, Augenbroe (2002) suggests that problems in mapping between different tools and procedures may contribute to the low performance of energy-efficient building. Loftness *et al.* (2009) revealed that significant gaps between the design intent and the performance of buildings and systems over time and occupancy shift could be caused by failures in the design, construction, management or use of buildings. These inefficient building performances can result in occupants' discomfort.

Occupants' comfort and comfort-related behavior can impact a building's energy and environmental performance and lead to the increasing operating energy, particularly in green buildings which are thought to be more fragile in their performance. Sartori & Hestnes (2007) highlighted that reducing the demand for operating energy appears to be the most important aspect for the design of buildings that are energy efficient throughout their life cycle. This is because operating energy represents by far the largest part of energy demand in a building during its life cycle. Therefore, having a building performance analysis which emphasizes on occupants' comfort particularly towards building's IEQ is crucial.

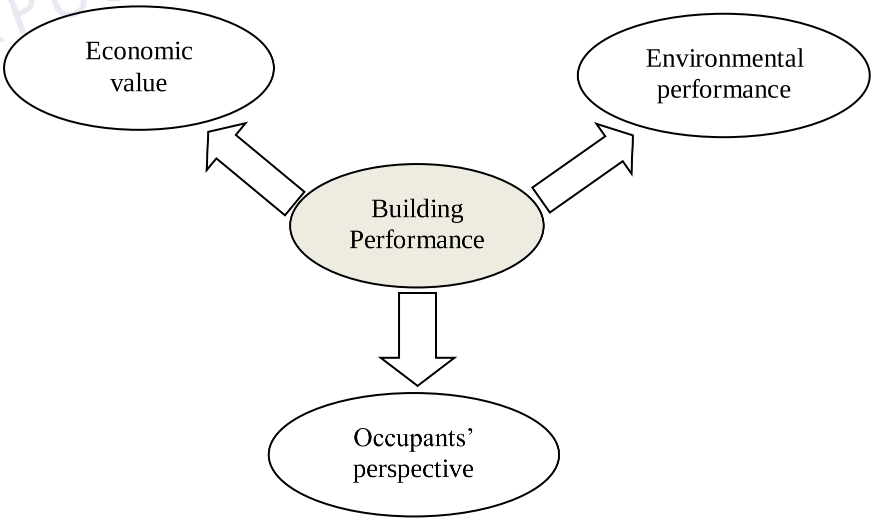

Figure 1.0: Building's performance evaluation perspectives

Leaman, Stevenson, & Bordass (2010) opine that building performance analysis can be studied from three different perspectives such as occupants, environmental performance and economic value as shown in Figure 1.0. Occupants' perspective towards building performance is focused on how well their needs are met; for the environmental performance, energy and water efficiency are assessed, and; economic value of building is in regard to whether the building makes economic sense, such as value for money or return on investment. Most of the time, client or building owner and designer are more interested in building's environmental performance and economic value since these two perspectives have a direct impact in reducing the energy cost. According to Vischer (2008), most design and construction decisions involve trading off building quality with construction cost. Thus, occupants' perspective is often neglected due to its insignificant economic value. Ibrahim (2003) suggested that it is important to ensure building quality and satisfaction of users' demands and expectations are attended by the design team during the design stage. Therefore, the co-operation between all members of the building design team should be organized to fulfill suitable environment that achieves the satisfaction of the user. Understanding the experience of the building from the occupants' point of view is as equally important as its technological performance (Leaman, Thomas & Vandenberg, 2007) as shown in Figure 1.1.

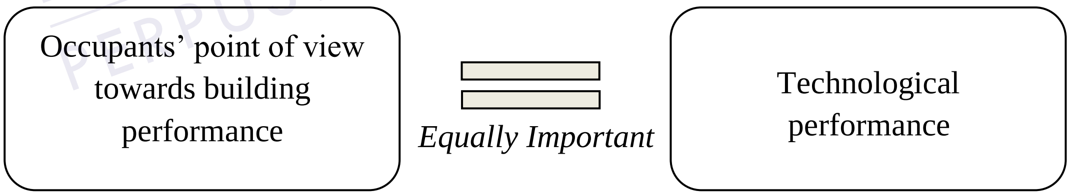

Figure 1.1: Occupants' point of view is equally important as its technological performance

This is because, not only can a poorly performing building affect occupants' wellbeing and productivity, subsequent measures needed to alleviate occupants' discomfort can also result in great expense in the building failing to achieve its efficiency targets. According to Hartkopf & Loftness (1999), fulfilling users' satisfaction in relation to the performance areas of IEQ criteria such as spatial, thermal, acoustics and air quality will be able to create considerably higher quality in living and work environments, while simultaneously reducing energy and environmental consumption. The key to good building usability is related to good relations between the people and the building, thus usability cannot be evaluated by assessing only physical parameters (Blakstad, Hansen, & Knudsen, 2008).

A fine balance should exist between optimizing *energy and resource efficiency* in green buildings and providing a *comfortable, healthy and productive indoor environment*. Fundamentally, green buildings often rely on natural conditioning to meet the comfort needs of end-users, passive strategies are employed to provide indoor conditions that are more able to adapt and link to the variation of temperature according to different season and climate. There are some environmental controls systems that can be designed either to accommodate active user's engagement, or to intelligently respond and adapt to changing external conditions with minimal user's engagement. Both approaches share a similarity, that they rely on effective feedback to inform users of design intention and the environmental consequences of their actions. Feedback is particularly important when environmental systems and control are new to designers, operators and users, and matching technological and management capability is crucial (Cohen *et al.*, 1999). Furthermore as occupants demand high performance of energy-efficient design with the aim of improving their comfort, *relationship between occupants' satisfaction and building's IEQ can be positively correlated with better building performance* (Wilkinson *et al.*, 2011).

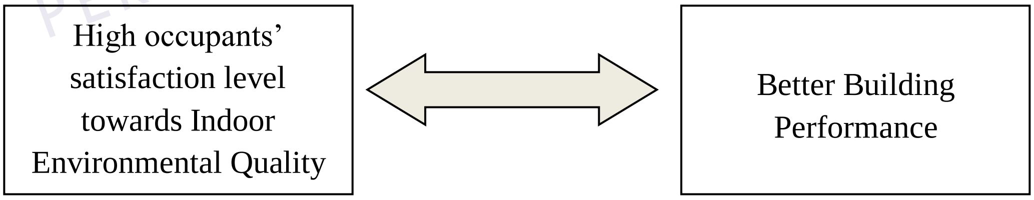

Figure 1.2: Correlation between occupants' satisfaction level towards indoor environmental quality (IEQ) and building performance

According to Ng (2005), there are four types of building performance evaluation methods focusing on occupants' perspective as shown in Table 1.0. These include Post Occupancy Evaluation (POE), Building in Use Assessment, Building Quality Assessment (BQA), and Total Building Performance (TBP).

Table 1.0: Types of building performance evaluation method

Building performance evaluation method	Description	Period of evaluation carried out	Variables of instruments involved
Post Occupancy Evaluation (POE)	• Post occupancy evaluation is the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time, usually **focused on building's IEQ** (Preiser & Visher, 2005).	• After occupancy (Preiser, 1995).	•**Standardized questionnaires** (e.g. to staff, business managers, facilities managers, customers); •**Interviews** (e.g. with staff, business managers, facilities managers, customers); •**Observations** (e.g. of staff at work, customers in use of the building); •**Physical monitoring** to provide a set of objective assessments. (Kantrowitz &Farbstein, 1996).
Building in Use Assessment	• Building-In-Use (BIU) assessment is a systematic rather than an analytical approach of yielding information about people and buildings that can be immediately put to use in solving building problems (Visher, 1989).	• After occupancy (Visher, 1989).	•Building-In-Use Assessment comprises a short, **standardized questionnaire** survey of office building occupants (Visher, 2005).
Building Quality Assessment (BQA)	• Building Quality Assessment (BQA) is a tool for scoring the performance of a building, relating actual performance to identified requirements for user groups in that type of building (Clift, 1996).	• After occupancy (Clift, 1996).	•Evaluated by a **trained assessor** (Clift, 1996).

Table 1.0: Continued

Building performance evaluation method	Description	Period of evaluation carried out	Variables of instruments involved
Total Building Performance (TBP)	• Total Building Performance (TBP) is a framework, through the comprehensive use of both objective and subjective field evaluations in all performance areas simultaneously, serves to understand the critical balance needed to simultaneously ensure all building performance mandates (Wong & Jan, 2002).	• After occupancy (Wong & Jan, 2002).	• The instruments include a range of tools (interviews, questionnaires, user surveys, checklists, measuring devices, remote probes, indicating and recording devices and computers) which transform a measurable characteristic of the building into information relevant to the building performance (Wong & Jan, 2002).

From Table 1.0, it can be concluded that POE encompasses the most comprehensive building performance evaluation from occupants' perspective compared to other methods. The variables of instruments involved in POE are questionnaire, interview, and observation which are related to occupants' perspective, and the period of assessment carried out is for after occupancy. Besides that, it also focuses on building's IEQ. Preiser & Vischer (2005) suggested that POE is different from other evaluation methods as it emphasizes on the needs of building occupants. Measures used in POEs include indices related to organizational and occupants' performance, workers' satisfaction and productivity, as well as the measures of building performance such as acoustic and lighting levels, adequacy of space, spatial relationships, etc. Hence, by the reasons stated above, POE is the most suitable building assessment method which studies from occupants' perspective. The importance of the research on POE has drawn researchers' attention in recent years and has led the development of various types of IEQ survey instruments. From a research done by Peretti & Schiavon (2011), they had identified ten IEQ surveys as shown in Table 1.1.

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Table 1.1: Types of Indoor Environmental Quality (IEQ) Survey (Peretti & Schiavon, 2011)

Survey name and references	Type of evaluation[1]	Objectives	Investigated topics	Number of applications	Physical measurement	Questionnaire structure
BUS (Building Use Studies) occupant survey	Long term evaluation	Assess how well buildings work, get feedback on occupants' needs and perceptions, improve services to occupants	Thermal comfort, perceived comfort, Indoor Air Quality (IAQ), occupant health, productivity (self estimated), personal control	Over 400 organizations and individuals worldwide	Not performed	24 environmental comfort questions, 10 on personal control, 17 on background info, health, productivity, and design.
HFSQ (Human Factors Satisfaction Questionnaire)	Long term evaluation	Effects of the physical environment on employees' behavior and attitudes. Survey on satisfaction with the physical environment and job satisfaction	Thermal comfort, IAQ, acoustic quality, structure organization and quality, health and security of occupants. Satisfaction with environmental factors.	N.A.	Not performed	Questionnaire is composed of 42 items
REF (Ratings of Environmental. Features) questionnaire	Long term evaluation	Research strategies for evaluating facility design, occupants' productivity, and organizational effectiveness	Thermal comfort, IAQ, acoustic quality, visual quality, and structure layout quality	7 administrative units and offices	Not Performed	Basic Survey: 24 items. Complete survey: 48 items
Building Assessment Survey and Evaluation (BASE) Study	Long term evaluation	Occupants' perceptions of IAQ and health symptoms	Workplace physical information, health and well-being, workplace environmental conditions, and job characteristics	100 buildings in 37 cities in 25 US states	Mobile cart: CO_2, temperature, RH, and supply air delivery. Real time monitors: CO, CO_2, temperature, RH, VOCs, $PM_{2.5}$,PM_{10}	33 questions and additional space for comments

Table 1.1: Continued

Survey name and references	Type of evaluation[1]	Objectives	Investigated topics	Number of applications	Physical measurement	Questionnaire structure
ASHRAE RP-884	Right-now evaluation	Develop an adaptive thermal comfort standard for ASHRAE	Thermal sensation acceptability and preference, air speed preference	160 buildings, approximately 21,000 subjects	Clothing insulation, metabolic rate, meteorological conditions, indoor air mean radiant temp., air speed, indoor humidity	Background questionnaire and thermal comfort questionnaire
CBE (Center for the Built Environment-UCB) survey	Long term evaluation with the possibility of right-now problems evaluation	Evaluation of building technologies and performance, quality benchmarking, and diagnosis	Office layout, office furnishings, thermal comfort, IAQ, visual quality, acoustics quality, building cleanliness and maintenance, general satisfaction plus customizable questions (eg. security, etc.).	600 buildings, approximately 60,500 subjects	Depending on which project the measurements are associated with. Level 1 and 2 of the PMP protocol	Core Survey (about 60 questions). Custom modules can be added to address issues not covered in the score questions
SCATS (Smart Controls and Thermal Comfort)	Right-now evaluation	Correlation between comfort temperatures and indoor/outdoor temperatures, behavioral analyses. Developing an adaptive control algorithm for Europe	Thermal comfort, IAQ, visual quality, acoustic quality, occupant productivity, general comfort	26 buildings in England, Sweden, Portugal, Greece and France. Approximately 4650 subjects	CO2 concentration, globe temperature, air temperature, relative humidity, illuminance, air velocity, noise level, meteorological stations for outdoor parameters.	Transverse questionnaire: 16 questions. Longitudinal questionnaire: 5 questions

Table 1.1: Continued

Survey name and references	Type of evaluation[1]	Objectives	Investigated topics	Number of applications	Physical measurement	Questionnaire structure
COPE (Cost effective Open Plan)	Long term evaluation	Evaluation of indoor environment satisfaction of occupants. How the physical environment influences organizational outcomes (job satisfaction, absenteeism, turnover, productivity)	Thermal comfort, IAQ, visual quality, acoustic quality, privacy, office layout, window access, lighting, work satisfaction, general satisfaction of workstation.	9 buildings	Physical measurements of each participant's workstation. Cart + chair system (illuminance, air velocity, CO, CO_2, THC, CH_4, TVOC, temperature, RH.	18 individual Environmental Features Ratings. 27 items in total.
HOPE Project	Long term evaluation	SBS research, benchmarking of healthy and energy efficient buildings	Thermal comfort, IAQ acoustic quality, occupant health	164 buildings in 98 EU states (69 offices and 95 apartments)	Detailed measurements of chemical, biological and physical parameters	5 comfort items, 7 SBS items and 12 illness indicators
Remote Performance Measurement, ICIEE-DTU	Long term evaluation with the possibility of right-now evaluation	Evaluation of IEQ satisfaction, health conditions and personal control by occupants. Characterization of occupants' perceptions and symptoms	Thermal comfort, IAQ, visual quality, acoustics quality, occupant productivity and health (SBS), personal control opportunities, general comfort and satisfaction	Approximately 30 buildings, 1500 people	Depending upon with which project the measurements are associated with	Background questionnaire: occupants' general perception of indoor environment. Instant Questionnaire: effects on occupants of any intervention performed

[1] Type of evaluation: long term evaluation refers to surveys where the aim is to investigate the occupant pas experience (eg. a week, a month, six month or a year). Right-now evaluation refers to surveys where the aim is to investigate the actual occupants' sensation)

Although the current IEQ survey instruments for POE are good for grading buildings, they are not inclusive enough when applied on energy-efficient building. The current IEQ survey instruments are unable to directly point out the problems of the building design which causes low performance of IEQ criteria, as the current IEQ survey instruments are not specifically meant for energy-efficient building. Fisk (2001) also argued that studies carried out by PROBE (Building Use Studies (BUS) survey) have failed to tackle all sustainability indicators and occupation styles during reviews.

If a comprehensive building evaluation which encompasses occupants' perspective is not being conducted to the energy-efficient building, *energy-efficient building design team would not be able to easily identify the problems that affect the building performance*. Since occupants are the end users of the building, the occupants' behavior while using the building can directly affect the building performance. Even though the development of energy-efficient building in Malaysia is still at the beginning stage, the industry players such developers, architects, and consultants should focus not only on the development of new energy-efficient building solely but the study on the existing energy-efficient building must not be neglected as well. Owing to this limitation on the POE, *a comprehensive evaluation framework is needed in order to reduce the gap between occupants and building's energy-efficient design*. For these reasons, the aim of this research is to determine the comfort level of energy-efficient (office) buildings in Malaysia, and to develop an evaluation framework for the identification of problems in respect to energy-efficient design which affects the occupants' comfort.

1.3 Research question

In accordance to the above problems, the research questions are as follows:

(i) How is it possible to identify problems affecting the occupants' comfort in term of energy-efficient design?

(ii) How reliable does the proposed approach in identifying problems affecting the occupants' comfort in terms of energy-efficient design?

(iii) What is the occupants' comfort level of the energy-efficient (office) building?

1.4 Research objective

The following objectives are identified in response to the research question:

(i) To propose an evaluation framework for the identification of problems which affect the occupants' comfort.

(ii) To determines the reliability and validity of the proposed evaluation framework.

(iii) To analyze the occupants' comfort level of the energy-efficient (office) building.

1.5 Scope of research

The scope of the research is focused on Indoor Environmental Quality (IEQ) criteria of energy-efficient building. The outcomes from the research carried out by Thomas (2010) highlight the importance of improving IEQ for occupants particularly through increased fresh air, daylight, glare control, access to views, and noise management. *Thus, the evaluation framework criteria for the energy-efficient design of the buildings are based on the key physical environmental parameters of Indoor Environmental Quality (IEQ) performance; such as thermal comfort, ventilation, lighting, and noise etc.*

The studied office buildings are selected from the energy-efficient building in Malaysia. Over the past decade, there is an increasing trend in the development of sustainable or energy-efficient building in Malaysia. The Ministry of Energy, Green Technology and Water (KeTTHA) building is the maiden energy-efficient building project in Malaysia; the building has even won the 2006 ASEAN building energy awards (Ministry of Energy, Green Technology and Water [KeTTHA], 2006). In the following years, the development of energy-efficient building in Malaysia continues to flourish, the development of the projects, such as Malaysia Green Technology Corporation and Energy Commission building or colloquially known as ST Diamond building are another two showcase energy-efficient building project initiated by the government following the success of the KeTTHA building. Both of the projects have obtained recognition from Malaysian sustainable building rating tools, Green Building Index (GBI) (Green Building Index [GBI], 2011).

Malaysia Green Technology Corporation building was certified with Green Building Index (GBI) certificate; and the ST Diamond building was awarded GBI Platinum and Green Mark Platinum which is the Singapore sustainable building rating tool (Koay, 2011). Although, the buildings have obtained the award and certified by sustainable building rating tools assessment, the efficiency of the building performance is still not at par as the expected performance. One of the Malaysian showcase energy-efficient building projects, Malaysia Green Technology Corporation office building has yet to achieve its desired performance even after three years in operation (Choong, 2009). Thus the proposed survey framework will be tested on the Malaysians' showcase energy-efficient buildings; the Ministry of Energy, Green Technology and Water (KeTTHA) building and Energy Commission building which are situated in Putrajaya, and Malaysia Green Technology Corporation building located in Bandar Baru Bangi.

According to Peretti & Schiavon (2011), building occupants are a valuable source of information for IEQ. Thomas & Hall (2004) found that good and robust environmental design begins with an integrated design approach that is cognizant of users' needs and expectations. *Hence, the sampling of research focuses on the occupants of the selected buildings. Random sampling was used to determine the sample size for each selected building*

1.6 Significance of the research

The research is important to the following parties/individuals:

(i) Ministry of Energy, Green Technology and Water (KeTTHA); Energy Commission, and Malaysia Green Technology Corporations as the owner of the building in the effort to improve the efficiency of their energy-efficient buildings respectively.

(ii) Contribute some relevant information regarding current energy-efficient building performance to the parties such as developers who are interested in developing construction projects related to the energy-efficient building.

(iii) Design team (architects or consultants) could use the information regarding the energy-efficient design which affects the occupants' comfort in preventing the repetition of past mistakes in the future development of energy-efficient building.

(iv) Academicians from civil engineering field could use the newly designed evaluation framework in gathering data regarding IEQ performance for energy-efficient building.

1.7 Structure of thesis

Chapter 1

In the first chapter, the aims, research questions and objectives are identified. The aims and objectives are developed from the identification of problems statement of the research. The needs to design a new environmental quality questionnaire for energy-efficient building are also outlined. Scopes of the research have been identified based on the nature and the requirement of the research. Lastly, significance of the research ended the discussion in Chapter 1, the importance of the research towards building industry development and engineering field has been justified.

Chapter 2

Chapter 2 is divided into 4 subtopics; energy-efficient building, Indoor Environmental Quality (IEQ), building performance analysis, and post occupancy evaluation. Energy-efficient building subtopic discusses the background and the definition of energy-efficient building, and the energy-efficient designs of the buildings are outlined. Common IEQ criteria problems encountered in energy-efficient building have been identified through previous researches. At the end of the chapter, the importance of implementation of questionnaire survey is justified. The significance of post occupancy evaluation carried out during occupancy stage is also outlined.

Chapter 3

The methodology of the research is divided into three phases; phase 1 involves preliminary study, literature review, and data collection. Phase 2 is regarding the survey framework development. In the second phase, the constructed survey framework EEBEQ validity is determined through content validation and pilot study. After the completion of phase 2, the modified EEBEQ survey questionnaire was tested on the case study building. The results obtained from the survey were then analyzed using sociological validation process, such as criterion validity, construct validity, and intra-class correlation coefficient (ICC).

Chapter 4

Data analysis conducted is detailed in this chapter; the collected data were analyzed according to the methodology procedures stated in Chapter 3. Interview and observation had been conducted while the site visits at the case study buildings had been carried out. Data gathered from previous researches provide important information regarding the problems affecting occupants' comfort in energy-efficient buildings. The collected data were then computed into questionnaire format EEBEQ. The EEBEQ was tested at the case studies building and its reliability and validity were then being determined thoroughly. The data were collected after questionnaire distributions were conducted, and the results were analyzed using SPSS software.

Detailed discussions are provided in order to examine the credibility of the EEBEQ and to achieve the research objectives.

Chapter 5

The research outcomes are summarized in this chapter; the findings of the research are discussed thoroughly. The findings of each objective are also further highlighted and summarized. This process was carried out with the information collected during data analysis. At the end of the chapter, future studies have been proposed for a further development based on current research. A building performance analysis model has been proposed for the designer and the management team of the buildings for a more effective post occupancy evaluation to be carried out in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter the literature review is divided into four parts; (1) energy-efficient buildings, (2) Indoor Environmental Quality (IEQ), (3) building performance analysis, and (4) Post Occupancy Evaluation (POE) method. The study is based on the information gathered from this literature review, which are building performance analysis, POE method, IEQ and energy-efficient buildings.

2.2 Building energy efficiency development

About 40 percent of the global energy consumption is used in buildings and this corresponds to one third of the global greenhouse gas emissions in both developed and developing countries (United Nation Environment Program [UNEP], 2009). Fortunately, the potential for greenhouse gas emissions reductions from buildings is relatively high (Levine *et al.*, 2007). Increasing energy efficiency in buildings is the answer to overcome the unfavorable trend of rising energy consumption. This is because, the energy efficient measures such as energy-efficient building are found to be effective in greenhouse gas emission reduction (Siong, Yun & Morris, 2011).

The concept of energy-efficient building has existed since the early 20th century; the construction of solar houses is one of the efforts towards reducing fossil energy consumption which will ultimately contribute to reduced greenhouse gas emission. The construction of the solar houses aims to realize zero fossil energy consumption in buildings heating systems. One of the examples of solar house is MIT Solar House I as shown in Figure 2.1. The solar house was built in 1939 and it is located at Cambridge, Massachusetts, United States. The solar house includes solar thermal collecting area and water storage system (Butti & Perlin, 1980). In 1955, the solar technology had been applied in the Bliss House located at Melbourne, Florida, United States; the solar technology has been used in the ventilation system (Bliss, 1955).

Figure 2.1: MIT Solar House I located at Cambridge, Massachusetts, United States (Artists Domain, 2010)

Another example of energy-efficient building is zero energy building (ZEB). In 1975, Professor Korsgaard from Danish Technical University together with his colleagues had successfully built a Zero Energy House (ZEH) at Thermal Insulation Laboratory. The building is the first solar heated house in northern Europe (Esbensen & Korsgaard, 1977). Following the success of ZEH in Denmark, many countries have started to develop their own energy-efficient buildings.

These early examples have been influential in current approaches to building design and indeed contributed to the definition and upgrade of building standards and regulatory codes. At present, voluntary standards for low-energy buildings using the principles of high insulation, good air tightness and heat recovery ventilation systems are increasingly popular, such as the scheme R-2000 in Canada (Natural Resources Canada, 2005), and Passivhus.dk a consulting company responsible for certifying passive house in Denmark (Passivhus.dk, 2012). This trend is now extending to other parts of the world.

The importance of reducing building energy consumption has elevated the development of energy-efficient building; each country has its own definition and standard to classify energy-efficient buildings. The variables of definitions and standards can be due to the different in climates and economy state of each country. Nevertheless, the approaches and guidelines by each party should contribute towards reducing building energy consumption and greenhouse gas emission by any means.

2.3 Definition of energy-efficient building

There is no specific definition for energy-efficient building whether in academic studies or at national levels. Each country in Europe has different definitions and scopes for energy-efficient building (Thomsen & Wittchen, 2008). However, its term could be traced from the previous research which related to energy-efficient building. In this section a definition of energy-efficient building will be derived from the summary of the previous researches related to the term of energy-efficient building used by researchers from various studies and fields.

Hauge *et al.* (2010) define energy-efficient building as building made to reduce energy consumption to different degree that includes low-energy buildings, passives houses, LEED buildings, and green buildings. Another research done by Zhang & Leimer (2011) entitled Low Energy Certificate – An Exploration on Optimization and Evaluation of Energy-efficient Building Envelope, refer green building as energy-efficient building. Furthermore, according to Krope & Goricanec (2009), the awareness of the importance of energy efficiency of building has brought to the development of energy-efficient (saving) building, and it includes low energy buildings, 3 liters house, passive house, zero-energy house, energy self-sufficient house, and plus-energy house. Thormak (2001), conducts a research to analyze the recycling potential of a low-energy dwelling (45 kWh (162 MJ) = m^2) in Sweden. In the research, the low energy building and passive houses are referred as energy-efficient building. In addition, Bauer & Scartezzini (1997), in their research on a simplified correlation method accounting for heating and cooling loads in energy-efficient buildings, one of the studied buildings is a simulated passive solar office room. According to Carassus (2008) energy-efficient buildings could be classified into three types of models: the Low Consumption model (eg. Passivhaus in German), the Energy and Environmental model (eg. LEED certified building) and the Energy Saving and Production model for example Zero Energy Homes.

While, a research conducted by Ahmed *et al*., (2009) in regard to the analyze of building performance data for energy-efficient building operation. During the research they have selected an energy-efficient building with many sustainable energy features such as solar panels, geothermal heat pumps and heat recovery systems as case study building. On the other hand, Kim *et al*. (2010) do an analysis of energy efficient building design through data mining approach. In their research, the energy-efficient building design for the building includes the building location, envelope (walls, windows, doors, and roof), heating, ventilation and air conditioning (HVAC) system, lighting, controls, and equipment. Kantrowitz (1984), carried out a research on energy-efficient building, describes energy-efficient building is a building designed with energy-efficient design such as HVAC and lighting system.

Based on the research done in previous studies, it is found that the researchers tend to form a collective agreement between one another in terms of their understanding of energy-efficient building. Energy-efficient building can be defined as a building using energy-efficient design strategies in reducing its energy consumption in order to achieve low energy consumption. It includes zero energy building, passive house, low energy building, LEED buildings, green buildings, energy self-sufficient house, plus-energy house and any other buildings that have been specifically designed with the aim of achieving energy-efficiency.

2.4 The variable of terminology for building with energy efficiency features

2.4.1 Zero energy building

According to Torcellini *et al.* (2006), zero energy building (ZEB) is defined as a residential or commercial building which greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. In 1975, Professor Korsgaard from Danish Technical University has successfully built a Zero Energy House (ZEH) at Thermal Insulation Laboratory as shown in Figure 2.2. The building is the first solar heated building built in North Europe (Gram-Hansen & Jensen, 2005).

Figure 2.2: A ZEH at Danish Technical University, Lyngby, Denmark (Seifert, 2006)

2.4.2 Passive house

Passive House concept is based on a holistic approach, improving the building envelope to a degree that allows for substantial simplifications of the heating system. Passive Houses offer increased comfort at affordable costs while significantly reducing the energy consumption (Feist *et al.*, 2005). This concept was developed in Germany in May 1988 by Bo Adamson and Wolfgang Feist, and has since then been widely and successfully used in Germany and Austria (as cited in Janson, 2008). One of the examples of passive house is the Passive House in Darmstadt

Kranichstein (Figure 2.3) which has been constructed in 1990/91 on design plans by a team of architects, Prof. Bott/Ridder/Westermeyer, for four private clients (Steinmüller, 2008).

Figure 2.3: Passive House in Darmstadt Kranichstein (Feist, 2006)

2.4.3 Low energy building

Low-energy building or simply low-energy refers to a building built according to special design criteria aimed at minimizing the building's operating energy (Sartori & Hestnes, 2006). According to European Commission (2009), low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation to lower heating and cooling energy. They may also use passive solar building design techniques or active solar technologies. The office building SD Worx as shown in Figure 2.4, is a low energy building which is located in Kortrijk, Belgium and consists of two office floors on top of a limited ground floor with building services (Breesch *et. al.*, 2004).

Figure 2.4: SD Worx, Kortrijk, Belgium (Breesch *et. al.*, 2004)

2.4.4 Green building

According to Burnett (2006), green building is a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life. Moreover, optimizes efficiencies in resource management and operational performance; and minimizes risks to human health and the environment. Genzyme Corporation as show in Figure 2.5 is a world-class example of green building construction, including advanced daylighting and thermal technologies. The building obtained LEED-Platinum due to its high efficiency and environmentally responsive architecture (Lockwood, 2006).

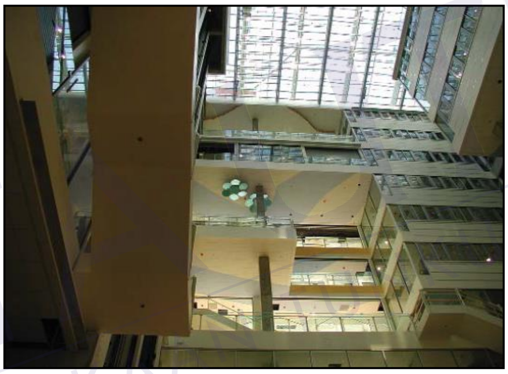

Figure 2.5: Genzyme Corporation Headquarter, Cambridge, Massachusetts, USA (Kats, 2003).

2.4.5 Energy self-sufficient house

One of the prominent examples of energy self-sufficient house is the Self-Sufficient Solar House (SSSH) in Freiburg, Germany (Figure. 2.6), built by the Fraunhofer Institute for Solar Energy Systems. Its entire energy demands for heating, domestic hot water, electricity and cooking is supplied solely by solar energy (Voss *et al*., 1996). According to Krope & Goricanec (2009), energy self-sufficient house is capable to generate energy for heating, cooking, water heating and the operation of home appliances through active utilization of solar energy.

Figure 2.6: Self-Sufficient Solar House (SSSH) in Freiburg, Germany (Bond, 2005).

2.5 The development of energy-efficient building in Malaysia

2.5.1 National Energy Policies

The first policy formulated concerning the energy sector in Malaysia was the Petroleum Development Act 1974. Subsequently, the national oil company, Petroliam Nasional Berhad (Petronas) was established with the responsibility for exploration, development, refining, processing, manufacturing, marketing and distribution of petroleum products. In the following year, the National Petroleum Policy (1975) was formulated under the Third Malaysia Plan (1976-1980). The objective of the policy was to encourage the utilization of the resource for industrial development efficiently, as well ensuring majority control in the management and operation of the industry was being implemented by the country. The Petroleum Development Act 1974 and National Petroleum Policy 1975 were considered the earliest energy sector policy in Malaysia. The policy pertaining to electricity sector was only formulated in 1979, is the National Energy Policy 1979. Malaysia's National Energy Policy (1979) aims to have an efficient, secure and environmentally sustainable supply of energy in the future as well as to have an efficient and clean utilization of energy. The three primary objectives of the country's energy policy are the supply, utilization and environmental objectives (Energy Policies of Malaysia, 2005).

In the years of 1980 and 1981, the National Depletion Policy (1980) and Four-Fuel Diversification Policy (1981) were formulated in order to achieve the National Energy Policy (1979)'s objectives. The National Depletion Policy (1980) is intended to conserve the country's energy resources, particularly oil and gas. As a complement, the Four Fuel Diversification Policy (1981) was then designed to prevent over-dependence on oil as the main energy resource. Its aim was to ensure reliability and security of the energy supply by focusing on four primary energy resources: oil, gas, hydropower and coal (Hitam, 1999).

In the year of 2000, the Four Fuel Policy was amended to become the Five Fuel Policy under the Eighth Malaysia Plan (2001-2005) where renewable energy (RE) was announced as the fifth fuel in the energy supply mix. Energy efficiency was also encouraged to prevent Malaysia from becoming a net energy importer which will affect her economic growth (Malaysian Economic Planning Unit, 2001). The Ninth Malaysia Plan was to strengthen the initiatives for energy efficiency and renewable energy put forth in the Eighth Malaysia Plan that focused on better utilization of energy resources (Malaysian Economic Planning Unit, 2006).

The New Energy Policy (2011-2015) under Tenth Malaysia Plan (2011-2015) emphasizes energy security and economic efficiency as well as environmental and social considerations. The Policy was focuses on five strategic pillars: (1) initiatives to secure and manage reliable energy supply; (2) measures to encourage energy efficiency (EE); (3) adoption of market based energy pricing; (4) stronger governance and (5) managing change. During the Plan period, EE initiatives will gain momentum with the formulation of the Energy Efficiency Master Plan (EEMP), setting of minimum energy performance standards for appliances and development of green technologies (Malaysian Economic Planning Unit, 2011).

2.5.2 Energy-efficiency programs

The formulated policies could not be realized without the proper implementation of energy-efficiency programs. Throughout the implementation period, various programs have been planned and carried out in order to realize each policy's objectives. According to a report of peer-review on energy efficiency in Malaysia, the energy-efficiency programs which have been implemented by the government includes, energy efficient building showcase models, auditing and retrofitting existing buildings into energy efficient buildings, Green Building Certification (Green Building Index) GBI, Malaysia industrial energy efficiency improvement project (MIEEIP), electrical equipments labeling programs, and energy efficiency awareness campaign (APEC Energy Working Group, 2011). The efforts of each programs shows the determination of government to implement energy-efficiency policies in Malaysia. The details of each program will be discussed in the following section.

2.5.2.1 Energy efficient building showcase models

The first energy efficient building that was built is the Low Energy Office (LEO), housing the Ministry of Energy, Green technology and Water. The LEO building was completed in 2004 and had won the ASEAN Energy Award in 2006 under the efficient building category. Other energy efficient buildings are the Green Energy Office (GEO), the first green building in Malaysia and the Diamond Building. These buildings serve as demonstration project to encourage more energy efficient and green buildings to be built in the future especially in the private sector.

2.5.2.2 Auditing and retrofitting existing buildings into energy efficient buildings

Besides building new model buildings, the Malaysian Government is also auditing and retrofitting some of its existing complexes to turn them from normal buildings to energy efficient and green buildings. Thorough energy audits were carried out in these complexes and it shows that a minimum of 20% reduction in electricity consumption could be achieved through simple retrofitting.

2.5.2.3 Green building certification (Green Building Index, GBI)

GBI is Malaysia green building rating system which was launched on 21 May 2009 to rank commercial and residential buildings according to six (6) criteria namely energy efficiency; indoor environment quality; sustainable site planning; materials & resources; water efficiency; and innovation. GBI is undertaken by the Building Professional Bodies. Buildings that met the minimum "greenness" level will be awarded with GBI Certificate. Higher levels of awards are GBI Silver, GBI Gold and GBI Platinum with GBI Platinum as the highest rank. The awards will expire in three (3) years to ensure that building owners maintained their buildings in a proper manner.

2.5.2.4 Malaysia Industrial Energy Efficiency Improvement Project (MIEEIP)

MIEEIP is a collaborative project on energy efficiency between the Malaysian Government and the United Nations Development Program (UNDP) – Global Environment Facility (GEF). The project started in 2000 and ended in 2007.

2.5.2.5 Electrical equipments labeling program

Malaysia electrical appliances labeling program was introduced in 2005 and covers several item namely the refrigerator, air - conditioner, television, motor, lamp and fan. The labeling program is being expanded to cover more electrical appliances. Appliances are labeled in a scale of five (5) stars with three (3) stars as the average and the more stars an appliance gets, the higher its efficiency is.

2.5.2.6 Energy efficiency awareness campaign

Awareness campaigns are carried out to educate the public on the benefits of energy efficiency and its practices. Besides the continuous awareness programs organized, a handbook on energy efficiency practices in the household was published and distributed to the public in 2008. This handbook serves as a handy reference to the household.

2.5.3 MS: 1525, Energy-efficiency in non residential buildings as regulatory

The energy efficiency programs such as energy-efficient building showcase models, auditing and retrofitting existing buildings into energy-efficient buildings, and green building certification (Green Building Index, GBI) show the government's determination in reducing the energy consumption in building sector. However, the success of each program could not have been achieved without the proper implementation from various industry players. Hence, a guideline is needed in order to let the people from the industrial to know exactly how to achieve the objectives stipulated in the energy policies advocated by the government.

MS: 1525, Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings has been outlined and is one of the approaches to achieve the objective of the policies. Besides that, as part of the efforts in promoting energy efficiency, Malaysia will amend the Uniform Building By-Laws (UBBL) to incorporate energy efficiency of buildings, where UBBL will likely to adopt Malaysian Standard MS 1525:2001 "Code of Practice on Energy Efficiency and use of Renewable Energy for Non-residential Buildings" which requires the yearly energy use Building Energy Index (BEI) of a commercial building shall be below 135 kWh/m^2 (Oh & Chua, 2010).

2.5.3.1 Building energy index (BEI)

Building operational energy efficiency can be measured through BEI. The BEI is the yearly energy consumption of the entire building divided by the air conditioned floor area (Chen, 2009).

$$BEI = \frac{TBEC - CPEC - DCEC}{GFAexcluding\ carpark - DCA - GLA \times \frac{52}{WOH}}$$

TBEC: Total Building Energy Consumption (kWh/year)
CPEC: Car park Energy Consumption (kWh/year)
DCEC: Data Centre Energy Consumption (kWh/year)
GFAexcluding car park: Gross Floor Area exclusive of car park area (m^2)
DCA: Data Centre Area (m^2)
GLA: Gross Lettable Area (m^2)
FVR: Weighted Floor Vacancy Rate of GLA (%)
52: Typical weekly operating hours of office buildings in KL/Malaysia (hrs/wk)
WOH: Weighted Weekly Operating Hours of GLA exclusive of DCA (hrs/wk)

According to Kannan (2007), in the Guidelines for Energy Efficiency in Buildings -1989 *(or now known as Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings)* published by the then Ministry of Energy, Telecommunications and Posts in December 1989, four typical buildings are defined to represent different expected levels of energy use in Malaysia. These four levels are: worst case, base case, proposed standard case and good practice case.

(a) Worst case building - represents buildings that are among the most energy intensive buildings that might be encountered in Malaysia today. BEI = 240 kWh/m^{2}yr.

(b) Base case building - reflect a typical range of construction and energy use features now prevalent in Malaysian new commercial building construction. BEI = 166 kWh/m^{2}yr.

(c) Proposed standard building - reflects the level of energy efficiency expected to be achieved by the proposed Guidelines. BEI = 136 kWh/m^{2}yr.

(d) Good practice building - represents a combination of energy efficient practice (including daylighting) that surpasses the requirements of the Guidelines proposed. BEI = 98 kWh/m^{2}yr.

2.6 Building's energy-efficient design

Energy-efficient components of energy-efficient building are specifically designed in order to emphasize building's energy efficiency. Such design is important to achieve low energy consumption of energy-efficient buildings. The energy consumption rates for each electrical component are vary from one and another due to their particular function and use. Light, air conditioning, and the direct plugged in electrical appliances have high energy consumption rate among all others electrical components. As so, the energy efficient components of energy-efficient building do not only include the building's architectural design but also the electrical components of the building, both of them could be classified as building's energy-efficient design. According to Kibert (2008), energy-efficient design of energy-efficient building can be categorized into passive design and active system. The term passive design and active system will be critically discussed in the following subtopics.

2.6.1 Passive design

Passive design is a building system design which depends on the source found at the site of building, such as sunlight, wind, and vegetations. The building systems include heating, cooling, lighting, and ventilation. Passive design is an approach to maximize the reduction of electricity consumption of building without taking account the use of external energy source other than energy from sunlight and wind. The efficiency of passive design fully depends on the sensitivity of the designer towards the factors affecting the building's electricity consumptions. Those factors are important because each building has different types of factors affecting its energy consumption, varied from their geographical condition.

2.6.1.1 Orientation and building shape

Identification of east-west axis at the building site is important for passive design approach; the large surface area of buildings' wall should be situated parallel to the east-west axis as shown in Figure 2.7. The purpose of the building position is to reduce direct sunlight from transmitting into the building area in a long period of time. Buildings are easy to overheat if the large surface area wall of the building is facing the east-west axis.

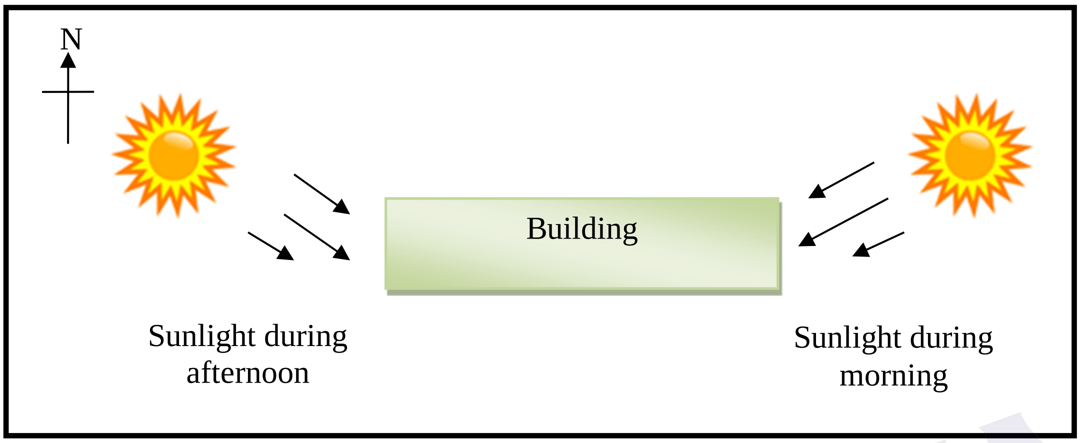

Figure 2.7: Orientation and building shape in warmer climatic zones.

Aspect ratio is used as the indicator to design the shape of the building, where aspect ratio is the ratio of the building's length to its width. Buildings in cold climate zones should have aspect ratio close to 1.0 or should be in square shape. This is because a square building will have the minimum skin surface area compared to its volume and this is important in heating situation.

The aspect ratio increases in the warmer climate zones. Thus, the buildings in warmer climate zones should have rectangular shape. This is because building area facing the west and east has a small surface area. The purpose of the design is to reduce the heat from transmitting into the building, so the windows on the east and west surface can be minimized (Ward, 2009).

2.6.1.2 Thermal mass

Thermal mass is an important aspect in passive design. Buildings in cold climate zones should use materials that are able to store solar energy to build the wall and ceiling during winter. Materials such as brick, concrete masonry, concrete, and adobe are able to absorb solar energy during the day and release it in the evening, when internal temperature begins to drop. For building in warmer climatic zones, solar passive cooling approach will be suitable. Buildings in such climates should have minimal mass for storing energy, and lightweight and be well insulated.

(a) Wall systems

The installation of wall for energy-efficient building should take into account the outer side of the building that is facing the direct sunlight and types of insulation suitable for the building's wall based on its surrounding condition. The installation of high insulation wall is important to the outer wall of the building; as it reduces the thermal mass from transmitting into the building.

(b) Window selections

The position for the window installation in the building and the selection of window glass are the major factors in determining the heat flow from outside of building through window (Wigginton, 2002). The windows which have low solar heat gain coefficient (SHGC) and visible transmittance (VT) are suitable to reduce the heat flow into the building through window glass.

(c) Roof

Roof is the area of the buildings that receive most of the sunlight. According to Cool Communities (2002), the temperature on the roof for shopping centre, warehouse, and office buildings can achieve up to 83 degree Celsius during summer. By using high albedo or high solar reflective material on the roof surface, temperature of the building can be reduced significantly. Apart from that, roof garden is also a suitable approach to reduce heat island effects in the building surrounding.

(i) Roofing materials

Solar reflective index (SRI) is the rating system for gauging the capability of a material to withstand the sunlight heat. The light color roof tile with 54 SRI can reflect 54 percents of sunlight. It is important to ensure the roof tile are always in the clean condition so that the light color of the roof tile will not become dark and then the heat absorption to the building will increase.

(ii) Roof garden

For roofs which are not installed with photovoltaic panel and solar thermal collector, green space is a good approach to replace the habitat and biodiversity destroyed during the construction process. Roof garden can also function in reducing the amount of water flow into the soil during raining season and avoiding flood occurs. Besides that, Feng *et al.* (2009) suggest roof gardens are able to reduce the heat absorption into the building during hot weather.

2.6.1.3 Daylighting

Daylighting is the important aspect in designing a high performance building. The main features for dayligthing technique are; the windows must see the light of the day, and glazing must able to transmit light, installation of daylight-activated controls, design daylight for the task and assess daylight feasibility for each portions of the building. The following discussion are based on the research carried out by Fox *et al.* (2008), the research was carried out at Research Support Facilities (RSF) building.

(a) Analogy of daylighting

Based on Figure 2.8, window facing towards direct sunlight has smaller window openings and the openings are near to ceiling, the purpose is to allow only diffuse light to reflect through ceiling surface and not heat. For the window openings not facing the direct sunlight, window openings at the area are larger in order to allow enough sunlight enter the building. Through this method, building will receive much of diffuse light and not heat.

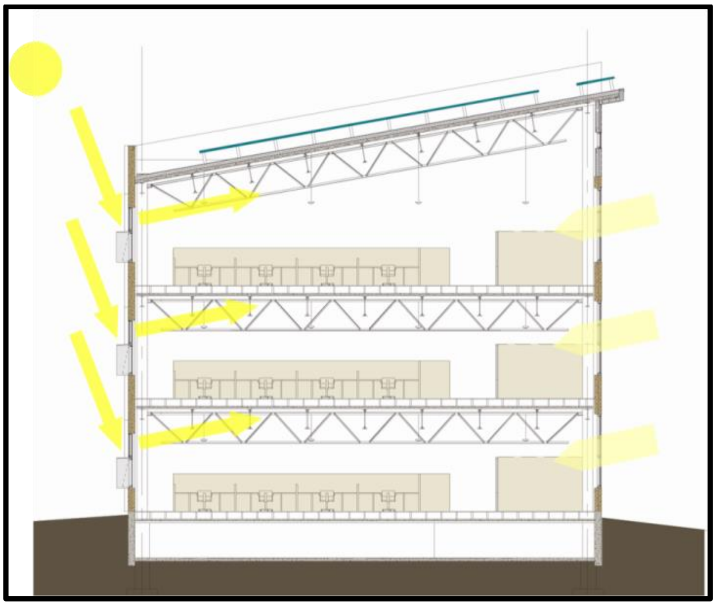

Figure 2.8: Analogy of daylighting showing the path of sunlight enter the building (Fox *et al*., 2008).

(b) Window design

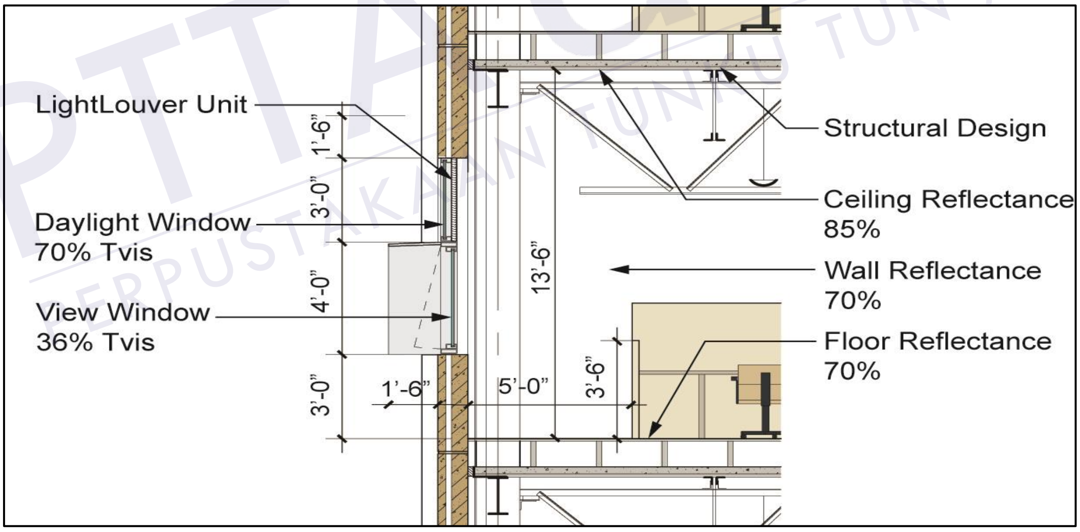

Figure 2.9: Side view of energy-efficient window (Fox *et al*., 2008).

Figure 2.9, shows the side view of window in energy-efficient buildings. Daylight window installed on the upper side of the window has 70 percents of visible transmittance. Thus, louver needs to be installed in order to reduce too much of sunlight entering the building. For the view window, low visible transmittance of 36 percents Tvis is required. Because of the low position of the window, louver installation is not suitable. Hence, thicker glass layer needs to be applied to the window area. The ceiling should be placed in the slanting position so that, sunlight enters through upper side of the window can be reflected into the building.

(c) Shading

The function of shades is to obstruct the sunlight from directly entering the building. This component is effective in reducing heat in the building. The installation of shades should face the source of sunlight for it to function accordingly. Figure 2.10 shows the position of shades of a building.

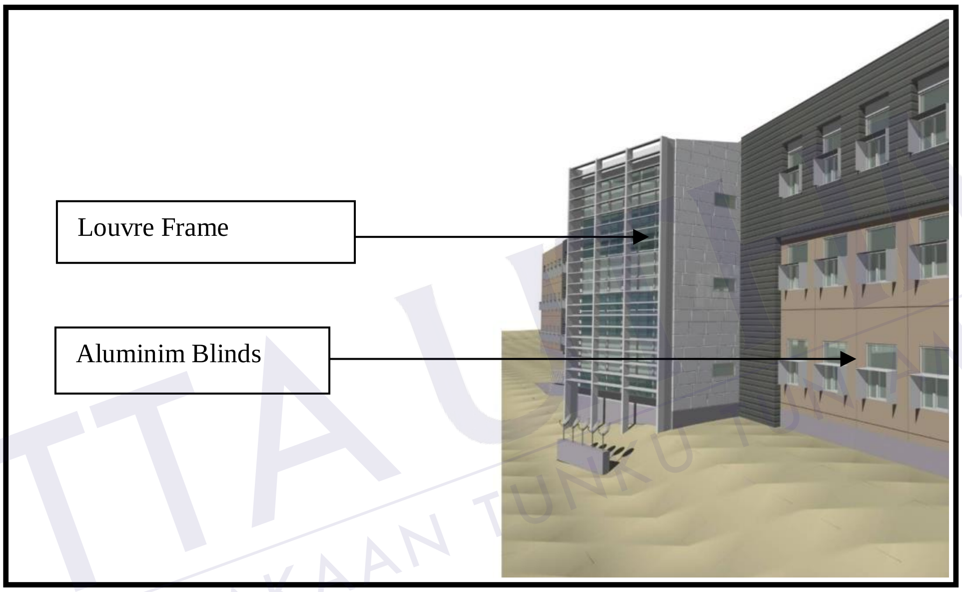

Figure 2.10: Position of shades of an energy-efficient building (Fox *et al.*, 2008).

(d) Vegetation

Trees planted at the building's surrounding, are capable to obstruct the sunlight from directly entering the building. It is also known as natural shading. Besides reducing thermal impact on the building, it can also serve as a recreational place for the occupants.

2.6.1.4 Passive ventilation/natural ventilation

Most of the time, ventilation of building is through the use of fans, separation, and control in order to flow the air from outside of the building into the building and at the same time to flow the same amount of air out of the building. In a more sophisticated design, air ventilation through natural force over mechanically is called passive ventilation system (Vaughn, 2006). There are two approaches for passive ventilation; venturi effects and lean building concept.

(a) Venturi effects

Passive ventilation can be achieved through venturi effects where high temperature of air will flow up in the vertical direction as shown in Figure 2.11.

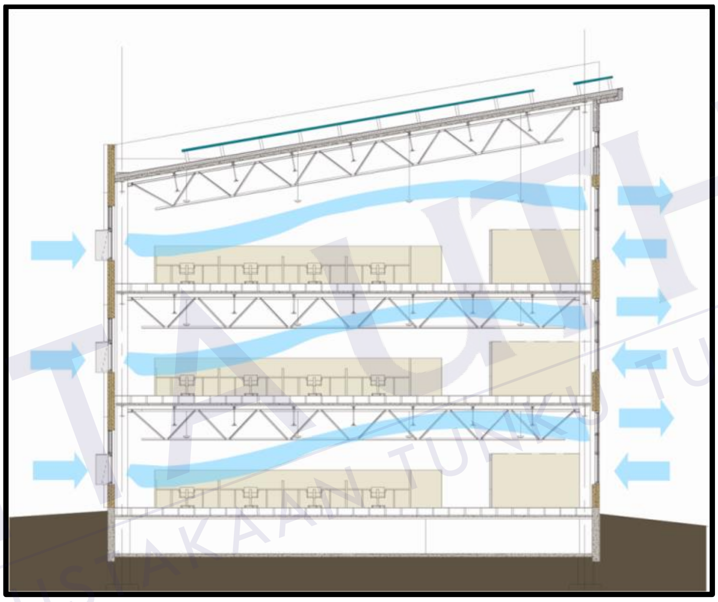

Figure 2.11: Venturi effects in energy-efficient building (Fox *et al.*, 2008)

(b) Lean building concept

Passive cooling strategy is an approach through the prevention of heat gaining with the purpose to reduce thermal load from outside of the building. Apart from reducing load thermal from outside of the building, passive cooling strategy can also reduce thermal load from inside the building caused by occupants and electrical appliances. The structure of the building must be able to store the remaining heat and flow the heat out through natural ventilation. Figure 2.12 shows passive cooling strategies for building.

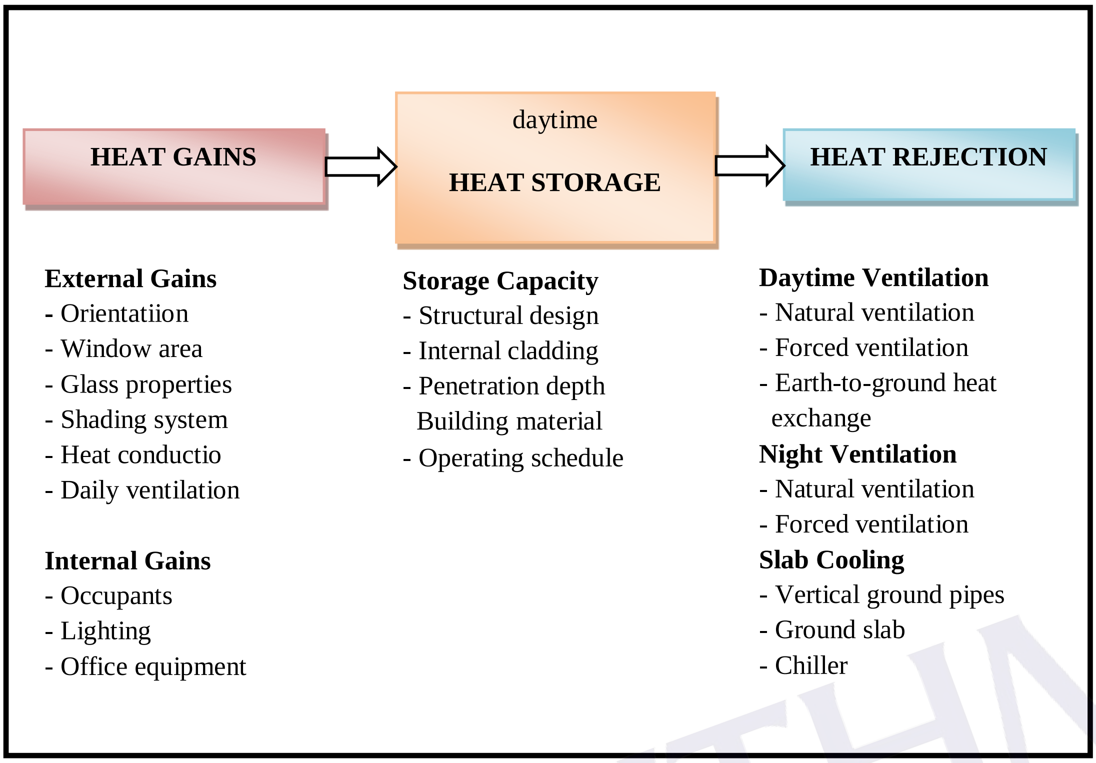

Figure 2.12: Passive cooling strategies (Kibert, 2008).

2.6.1.5 Solar thermal collectors

Solar thermal collectors are applied in the passive solar design in most of the time. Generally there are three types of solar thermal collectors; formed thermal collectors, flat plate collectors, and evacuated tube collectors (Wilson & Burgh, 2008).

(a) Formed thermal collectors

This type of solar collector is made of polypropylene, EDPM, or ETP plastics and contains tube or formed panel designed to flow water and heat by sunlight. This panel is not suitable for yearly usage in the cold climatic zones. This is due to the lack of insulation which will reduce the effectiveness of the system when the surrounding temperatures are lower than the heated liquid temperature.

(b) Flat plate collectors

This type of heat collector has thin absorber sheet in black color and the high conducive materials such as copper weld with grid or liquid tube arrangement. This collector is placed in the thermal insulation box and sealed with plastics or glass cover. The liquid flows through the tube to remove the heat from the absorber and sends to thermal insulation water tank, thermal exchanger, or other tools to remove thermal.

(c) Evacuated tube collectors

The functions of evacuated tube collectors are to reduce the thermal lost to the surrounding temperatures. Thus, it is able to produce high temperature water compared to flat plate collectors. Each of the tube contains its own collector. Usually it will be painted or coated with a layer of copper, and placed in the tube with double layer mirror which contains half vacuum inside of it. In the common design, the liquid will be flowed into two of the tube, one of them is to support various purposes and the other is to flow into the hot water storage tank that might use heat exchanger to separate water from the used hot water. Evacuated tube collectors produce more solar energy compared to others types of panel.

2.6.1.6 Internal load reduction

After reducing the electricity usage in building through high efficiency building design as discussed in the previous subtopics, the reduction of electricity consumption in building can be improved by reducing building internal load such as from computer, computer software, copier, and other appliances. This is because, the appliances consume high energy. Apart from that, upsized electrical wiring can reduce the energy lost while transferring the electricity from grid to appliances.

(a) Plug load reduction

In most of the office buildings, the highest plug load is from the desktop computers. One of the alternative ways to reduce desktop computer plug load is by replacing them with laptop which has high energy efficiency and long battery life. Laptop has 40 watt, or only 25 percents of the energy consumption of desktop computer.

(b) Miscellaneous plug loads

Electrical loads for printers, scanners, copiers and fax machines also contribute to higher building energy consumption. The replacements of high energy efficiency devices are needed. Devices approved by Energy Star are energy-efficient devices suitable to replace the high energy consumption appliances or devices.

(c) Plug load control

Plug load control is a strategy used to reduce electricity consumption by device while not in used. However, there are some of the devices such as fax machine, main server, and building surveillance system need to be active all the time. Thus high efficiency is the criterion to select suitable devices. The control of the plug load for office building appliances that are not always in use is one of the strategies to reduce the energy consumption. For example, laptop will be automatically shut down after not in used. Devices such as copiers and scanners are only turned on when in use.

(d) Upsized electrical wiring

All circuits lose small amounts of energy through resistance as powers flow through the wiring. If wires are upsized, resistance in the wires is lower and losses are reduced. Hence, upsized electrical wiring is one of the approaches to reduce the energy consumption in buildings.

2.6.2 Active system

Active system is an approach involving mechanical and electrical means to increase energy efficiency in building after the passive design strategies have been applied. The components of the mechanical system include Heating, Ventilation and Air Conditioning (HVAC), and electrical system is the electrical appliances installed in the building such as light and electrical motor.

2.6.2.1 Active mechanical systems

After the passive building designs have been fully optimized, indoor building environment is still affected by internal heat load. The internal heat load is due to the number of occupants and appliances use in the building. The numbers of occupants for certain types of building such as classroom are constantly changed; hence it is difficult to reduce the heat load. For office building, most of the heat loads are from office buildings appliances, lighting, and other electronic devices. Active mechanical systems are able to reduce heat loads in the office building due to the use of such appliances. There are various types of Heating, Ventilation, and Air-Conditioning (HVAC) systems that can be used to form an indoor environment that fulfills occupants' needs. The selection of the system is based on function, building size, climates condition, and the building load profile. Types of main appliances in HVAC system, such as, chillers, air distribution system, energy recovery system and carbon dioxide detector for ventilation purpose will be discussed in the following subtopics.

(a) Chiller

The efficiency of chiller can be increased more than 50 percents through the combination of new technologies such as direct digital control (DDC), the improvement of design, inspection, and operation. The high performance chillers have efficient design and components, detailed installation, and are constantly inspected for its operation. There are four types of chiller such as:

(i) Centrifugal, primarily large tonnage above, 1,000 kW or 300 tons
(ii) Screw (50 to 400 tons) (170 to 1360 kW)
(iii) Scroll (up to 50 tons) (170kW)
(iv) Reciprocating (up to 150 tons) (510kW)

(note: 1 ton equals 12,000 BTU/hour of cooling capacity, or 3.4 kW)

Nowadays, there is high performance chiller such as Trane CVHE/F Earth Wise centrifugal chiller which has high energy efficiency. The energy consumption rate for the chiller is only 0.45kWh per ton cooling. There are five design strategies for a high-efficiency chiller plant:

(i) Focus on chiller part load efficiency

There are three methods for improving chiller plat load efficiency; specify a chiller that can operate with reduced condenser water temperature, specify a variable-speed drive (VSD) for the compressor motor, and select the number and size of chillers based on anticipated operating conditions.

(ii) Design efficient pumping systems

Energy use in pumping systems may be reduced by sizing the pumps based on the actual pressure drop through each component in the system, as well as the actual peak water flow requirements, accurately itemizing the pressure losses through the system and then applying a realistic safety factor to the total. Moreover, fluid velocities should be kept low; temperature differentials across the chiller should be as high as possible; the piping system should be kept simple and unnecessary devices such as valves should be minimized, the possibility of using a variable-flow system should be evaluated; and high-efficiency pumps and motors should be specified.

(iii) Properly select the cooling tower

Proper sizing and control of cooling towers is essential to efficient chiller operation. Cooling towers are often insufficiently sized for the task. An efficient cooling towers should be specified using realistic wet-bulb sizing criteria; an induced draft tower, if space permits, intelligent controls; and sequences of operation that minimize overall energy use.

(iv) Integrated chiller controls with building EMS

Although modern chillers are computer-controlled and have considerable intelligence to assist their operations, they should be integrated with the building's energy management system (EMS) to provide the capability to optimally operate the entire building energy plant. To accomplish this integration, the designers should specify an "open" communications protocol, use a hardware gateway, measure the power of ancillary equipment, and analyze the resultant data.

(v) Commission the system

Commissioning the chiller system is needed in order to reduce the technical problems during the operation of chiller. The process of commissioning a chiller could be functionally testing it under all anticipated operating modes to ensure that it performs as intended.

(b) Air distribution system

Air distribution system comprises of air handlers, electric motors, ductwork, air diffusers, registers and grilles, energy and humidity exchangers, control boxes, and its control system. The design of air distribution system should use the same approach as for the chiller plant to deliver the precise capability needed and to do so efficiently across a wide range of operating condition.

(i) Variable air volume (VAV) system

VAV system delivers the precise volume of air needed to meet the actual load of a building space. VAV systems offer better energy performance than constant volume systems. VAV systems are now virtually a standard design practice. Yet, even greater efficiency gains can be made through careful selection of equipment and system design.

(ii) Variable air volume diffusers

Temperature in rooms using VAV system could be different and can cause space conditions farther from the thermostat and VAV box location to be uncomfortable. VAV diffusers are capable to modulate the amount of conditioned air delivered to a space by eliminating the inefficient of overheating or overcooling spaces.

(iii) Low pressure duct design

Duct size should be increased to reduce duct pressure drop and fan speed. The improvement of the aerodynamic of the flow paths can reduce the resistance in the duct system. The increase of ducting size is able to reduce the air velocity, which in turn permits reductions in fan speed and yield substantial energy savings.

(iv) Low-face velocity air handlers

The reduction in air speed across the coils can cause the pressure to drop, and allowing the use of a smaller fan and smaller VFD, thus, reducing the costs of the components. Higher chilled water temperature occurs when air travelling at a lower velocity remains in contact with cooling coil longer, and hence can reduce the size of chilled water plant.

(v) Proper fan sizing and VFD motors

Fans should be properly sized to match the calculated load. The fan motor’s speed and torque should be electronically controlled to continually match fan speed with changing building-load conditions. Electronic control of the fan speed and airflow can replace inefficient mechanical controls such as inlet vanes or outlet dampers.

(vi) Displacement ventilation systems

Displacement ventilation system is designed to introduce conditioned air into an under floor plenum formed by a raised access floor. The air then moves upward into the occupied space via grilles or registers in the access floor. This strategy slowly pushes the conditioned air into the occupied space, displacing the air in the room vertically with minimal mixing, thus providing significant energy savings.

(c) Energy recovery systems

Fresh air is important for the comfort of a room. To maintain the fresh air inside a room, the quantities of fresh air brought into the room should similar to the amount of air exhausted from the room. However, if the outside building temperature is higher than inside building, devices to reduce the temperature are needed in order to prevent overheating inside the building. Another approach is to simply use outside air directly for conditioning the building when outside conditions are just right for ventilation purpose. Technologies such as economizers and energy recovery ventilators (ERVs) are developed to use outside air for conditioning and to exchange energy between fresh air intakes and exhaust air streams.

(i) Economizers

Economizer is an approach that enables the use of outside air to cool the building when the weather conditions are appropriate. The process can be initiated when the outside air temperature and humidity are in the same range as conditioned air delivered to the space would be, and then duct the outside air to replace the conditioned airstream. Through this approach, energy consumption can be reduced when the chillers and chilled water are turned off.

(ii) Energy recovery ventilators (ERVs)

Many high performance building use the energy recovery ventilators system as part of their energy-efficient design. ERV is an energy and humidity exchanger that employs desiccant technology for its functioning. ERV devices are placed between fresh airs and exhaust air streams. Moving energy and humidity between the two streams save significant quantities of energy.

(d) Ventilation air and carbon dioxide sensors

Building installed with carbon dioxide sensors can function efficiently in terms of air ventilation. Fresh air is brought in to the buildings based on the buildings' actual condition (carbon dioxide level). Through this approach, the buildings can save energy used for ventilation purpose.

2.6.2.2 Electrical Power systems

Electrical power system is one of the buildings components that has high energy consumption apart from Heating, Ventilation and Air-Conditioning (HVAC) system. The recent development of lighting technologies has produced high efficient lighting with low energy consumption compared to the conventional lighting. Apart from lighting, electrical motor used to generate fans, pump, and other appliances also have high energy consumption. Hence energy-efficient motor is able to reduce energy consumption in building if applied effectively (Fowles, 2008).

(a) Lighting systems

Lighting systems consume large amount of energy in buildings. Thus, the aim of the building design should focus on reducing the usage of artificial lighting and maximize the use of daylighting. These approaches need to be integrated with the high efficient lighting in order to achieve low energy consumption target.

(i) Fluorescent lighting

Fluorescent lighting is the best source for most building lighting applications due to its efficient characteristic and can be switched and controlled easily. Modern linear fluorescent lamps have good color rendering and are available in many styles. The classifications of lamps are based on length, form (straight or U-bend), tube diameter (eg. T-8 or T-5), wattage, pin configuration, electrical type (rapid or instant-start), color rendering index (CRI), and color temperature. Table 2.1 shows fluorescent light fixture characteristics.

Table 2.1: Fluorescent light fixture characteristics (Kibert, 2008).

Lamp type	**T-12**	**T-12 ES**	**T-8**	**T-5**
Watts	40	34	32	54
Initial lumens	3,200	2,850	2,850	5000
Efficacy(lumens/watt)	80	84	89	93
Lumen depreciation	10%	10%	5%	5%

Based on Table 2.1, T-5 lamp is operated with electronic ballast and offers continuous dimming. T-5 lamp has 93 lumens/watt of its efficacy compared to 89 lumens/watt for T-8 lamp.

(ii) Fiber-optic lighting

Fiber optic lighting uses light-transmitting cable fed from s light source in a remote location. A fiber optic lighting system consists of an illuminator, fiber optic tubing, and possibly fixtures for end-emitting uses. Fiber-optic lighting provides many benefits and eliminates many problems encountered with conventional lighting system.

(ii) LED lights

Light-emitting diodes (LEDs) emit light when current is passed through the semiconductors, and electricity is converted to light without generating heat. Due to this characteristic, LED lights are applied in the energy-efficient building as an alternative lamp which can reduce the building energy consumption.

(b) Lighting controls

Lighting controls should include integration system which can detect human presence switch off when no human presence is detected. Apart from that, lighting controls should have dimming capabilities where light intensity is based on the daylighting conditions.

There are two types of daylighting control systems, dimming and switching. Dimming controls vary the light output over a wide range to provide the desired light level. On the other hand, switching controls turn individual lamps off or on as required. Thus sensors are needed in order to detect the presence of human when the above approaches are applied.

(c) Electric motors

Electric motors are important components of modern buildings, as appliance such as fans, pumps, elevators, and host cannot function without electric motors. Energy-efficient electric motors are made from high quality material and have sophisticated design that increases its efficiency of operations.

2.7 Indoor environmental quality (IEQ)

As mentioned earlier, energy-efficient building has better indoor environmental quality (IEQ) compared to conventional building. However, some of them do not perform as expected. The buildings' IEQ is important to the occupants' health especially for office buildings which could affect the occupants' productivity if their work area has low IEQ. According to Evans & Stecker (2004), both acute and chronic exposure to noise, crowding, traffic congestion, and pollution are capable of causing learned helplessness in adults and children. In the following section, common IEQ problems in energy efficient building will be identified from previous studies and each of the IEQ deficiency will be further discussed.

2.7.1 Energy-efficient design problems affecting occupants' comfort with respect to IEQ criteria

Yu *et al.* (2009) carried out a research on air conditioning systems and indoor air quality control for human health and found ineffective air conditioning systems could contribute to poor indoor air quality. Low indoor air quality poses a threat to human health, particularly for the everyday users. The importance of occupants control over room temperature is further supported by a research done by Steemers & Manchanda (2010). Based on the findings of their research, the results demonstrate that increased energy use in the case study buildings is associated with increased mechanization such as centralized air condition/ventilation, and reduced occupants' control. The results show that the reduced control in turn is related to reduced occupant comfort and satisfaction.

A research done by Thomsen *et al.* (2005) in 12 solar low energy buildings reveals some of the problems encountered by the occupants toward buildings' indoor environmental quality. The main reason for the high indoor temperature in Danish house is due to lack of cross ventilation and lack of solar shading. Apart from that, mechanically ventilation system could cause noise and draught problems. Another project in Norwegian shows noise in the living room caused by the heat pump compressor.

The research done by Wong *et al.* (2005) in Singapore shows that fully glazed facade that has been increasingly used in the country due to the advantages of reducing lighting energy consumption has caused higher energy consumption and thermal discomfort owing to higher solar gain. The use of double glazed façade system with ventilation system is one way to resolve these problems.

Mumma (2002) in his research identifies that radiant cooling system facing the design issues can contribute to the problems such as condensation and radiant asymmetry. Condensation may occur when the chilled ceiling panel's temperature is lower than its enclosure's temperature. Meanwhile, radiant asymmetry will occur when most of the enclosure is at 25.6 degree Celsius and the chilled ceiling panels are at approximately 15.6 degree Celsius, a 10 degree Celsius radiant asymmetry temperature exist.

Lim *et al.* (2006) research found that in the radiant floor cooling system, floor surface condensation and comfort are major concerns for field application. To prevent floor surface condensation, the supply water temperature could be manipulated according to the dew point temperature in the most humid room and in an individual's room where the water flow rate (on/off control) can be controlled.

Zhen & James's (2006) research on the building with radiant cooling system shows that local discomfort is the identified problem that can cause occupant's discomfort. Their survey results revealed that about 14-22% of participants were in the arm-hand and leg-foot region.

According to Raja *et al.* (2001), a field study of thermal comfort of workers in natural ventilated office buildings in Oxford and Aberdeen, UK was carried out and found out that occupants who have greater access to controls (e.g. those close to a window) report less discomfort than those who have less access (e.g. away from the window).

A research carried out by Hua *et al.* (2011) on a LEED - Gold building shows that occupants desired more control over the light and shading in their workplaces. Due to the fact that large blinds controlled with thin strings are difficult to operate, blinds are not often adjusted by the occupants to support visual comfort. Furthermore, some of the occupants even delamping their lighting fixtures voluntarily in order to make the environment more suitable for work. The findings show that occupants prefer to change lighting condition themselves, rather than have them automatically controlled and it is consistent with findings from the studies done by other researchers.

Galasiu & Veitch (2006) conducted a research on occupant preferences and satisfaction with the luminous environment and control systems in daylit offices, concluded that improving the energy-efficiency of commercial building lighting should include better use of daylight, but that will require the development of control systems that result in luminous conditions that are suitable to occupants. Their research shows that limitations of current knowledge about how people respond to daylight, and particularly how they respond to automated photocontrolled lighting and shading controls are the main problems facing by the daylit office design.

A study of a glazed office building by Altan *et al.* (2008), shows that high intensity solar radiation transmitting through the glazed areas can cause unwanted glare effect and interior overheating during warm and sunny days, although glazed facades are able to maximize the daylighting with high indoor luminance in an open plan floor spaces in buildings.

Bülow-Hübe's (2008) study on glazed office building in Sweden has identified that very large windows do not mean that the light is automatically better. This is because, the larger the window area, the greater is the chance that a window might create glare. It can be difficult to achieve a glare free environment without additional measures, for example by adding interior curtains or blinds.

Taeyon & Jeong (2011) investigated the effects of indoor lighting on occupants' visual comfort and eye health in green building found that the indoor lighting and visual environment of the building are poor and the visual annoyance is caused by glare, darkness, unqualified shade materials and logic error of shade.

A case study of Kresge foundation office complex in Troy, Michigan by Goins *et al*. (2010) shows although the building acquired LEED-platinum rating, the building is still facing significant problems in the acoustics performance. Occupants have low satisfaction towards the acoustics performance of the building although other IEQ criteria have high satisfaction score. The research also reveals that sound privacy is the main concern of the problem.

A review on manually-operated window shade patterns in office buildings done by O'Brien et al. (2012) indicates that difficulty to operate shades is the reason occupants of the building's lack of using shades in reducing thermal discomfort or glare and tend to rely on energy-consuming technology to achieve thermal comfort and reducing glare. Another research also shows over glazing can contribute to thermal discomfort. According to Persson *et al.* (2006), a larger glass area of 40% means more than double the cooling power compared to the case of a 50% reduced window area.

Foster & Oreszczyn (2001) carried out a research on occupant control of passive system of venetian blinds. The research shows majority of the blinds tend to be kept down most of the time. The reason for this situation to occur is due to the over glazing of the building. A much smaller window therefore can reduce thermal discomfort and glare problems.

A research done by Wilkinson *et al.* (2011) shows that most of the energy-efficient buildings share a common problem, which is lack of privacy. The research found that high levels of dissatisfaction are related to the area of privacy within the offices with more than one respondent noting: 'lack of privacy in office is the biggest problem' and 'critical problem - lack of privacy'. The overall level of satisfaction is very low for privacy. It should be noted that lack of privacy is closely related to the poor acoustic performance and high rates of sound transmission from office to office and corridor to offices.

Lee's (2010), study investigating office layout affecting privacy, interaction and acoustic quality in LEED – certified buildings reveals that people in high cubicles have shown significantly lower satisfaction and job performance in relation to visual privacy and interaction with co-workers than both enclosed private and enclosed shared office types.

Muehleisen (2010) has identified acoustics as the least satisfaction indoor environmental criteria for energy-efficient building after post occupancy evaluation have been carried out in 181 buildings. The results show that excessive noise, speech clarity and privacy are the types of acoustics problem in energy-efficient building.

Jensen *et al.* (2005) have analyzed acoustic satisfaction in office environments in buildings surveyed by the Center for the Built Environment (CBE). The study reveals that office workers are significantly more dissatisfied with the lack of speech privacy than with the level of noise. Occupants in open office environments are more satisfied than the occupants of either type of cubicle with noise and speech privacy.

The current energy-efficient envelope is air tightness with minimal infiltration/exfiltration to reduce energy losses. The tight envelope can aggravate potential Indoor Air Quality (IAQ) problems (Wendt, *et al*., 2004). A research on indoor air quality in low carbon emission house conducted by (Yu & Kim, 2012) shows volatile organic compounds (VOCs) in energy-efficient house are higher than the conventional house. The concentration of VOCs was maintained the rest of the 7-year monitoring showing the ineffectiveness of the ventilation system for removal of VOCs in the indoor environment of the air-tight house and there was always a “reservoir” of VOCs exist in the house.

Pank *et al.* (2008) find that building façade air-tightness for tall green building is a major issue where pressure differentials from higher winds at the top of a building can cause problems with controlling internal temperatures and drafts. Using the right window façade such as double glazing window can reduce the differential of pressure.

Paul *et al.* (2010) carry out a research on the effect of mechanically induced ventilation on the indoor air quality of building envelopes. The research findings show the dust particle concentration level and the interior wall moisture content values increase by 20–50%. Crump *et al. (*2009) state that homeowner do not use the mechanical ventilation systems on a continuous basis because of concerns about wasted energy, noise and discomfort caused by cold draughts.

2.7.2 Thermal comfort, lighting, air quality, acoustics

The common IEQ problems in energy-efficient buildings are thermal comfort, lighting, air quality, and acoustics as shown in Table 2.2. In this section further discussion will revolve around the four major IEQ criteria as mentioned above.

Table 2.2: Energy-efficient design problems affecting occupants' comfort with respect to IEQ criteria

No.	Researchers	Part of energy-efficient design	IEQ criteria	Identified problems
1.	Steemers & Manchanda (2010)	• Air conditioning system • Natural ventilation system	• Thermal comfort	• Lack of occupants control over air conditioning system; • and ventilation system (window) caused thermal discomfort.
2.	Wong *et al.* (2005)	• Window	• Thermal comfort	• (Large window area) Fully glazed façade cause thermal discomfort due to high solar gain.
3.	Mumma (2002)	• Radiant ceiling cooling system	• Thermal comfort	• Condensation • Radiant asymmetry
4.	Lim *et al.* (2006)	• Radiant floor cooling system	• Thermal comfort	• Floor surface condensation • Radiant asymmetry caused local discomfort
5.	Zhen & James (2006)	• Radiant floor cooling system	• Thermal comfort	• Local discomfort (radiant asymmetry)
6.	Raja *et al.* (2001),	• Natural ventilation system	• Thermal comfort	• Lack of occupants control over ventilation system (window)
7.	Hua *et al.* (2011)	• Artificial lighting • Window shades	• Lighting	• Lack of occupants control over artificial lighting and; • window shades of the building
8.	Galasiu & Veitch (2006)	• Artificial lighting • Window shades	• Lighting	• Limitations of current knowledge about how people respond to daylight (eg. artificial lighting and; • Window shades control).
9.	Altan *et al.* (2008)	• Window	• Lighting • Thermal comfort	• High intensity solar radiation transmitting through the glazed areas can cause unwanted glare effect and; • interior overheating
10.	Bülow-Hübe (2008)	• Window	• Lighting	• The larger the window area, the greater is the chance that a window might create glare
11.	Wilkinson *et. al.* (2011)	• Office layout	• Acoustics	• Lack of privacy • Noise problems
12.	Lee (2010)	• Office layout	• Acoustics	• Poor visual privacy • Noise problems

Table 2.2 (continued)

No.	Researchers	Part of energy-efficient design	IEQ criteria	Identified problems
13.	Muehleisen (2010)	• Natural ventilation system • Window	• Acoustics	• Excessive noise • Lack of speech clarity and; • privacy
14.	Taeyon & Jeong (2011)	• Window • Window shades	• Lighting	• Glare, darkness • Unqualified shade materials • Logic error of shade
15.	Goins *et al.* (2010)	• Office layout	• Acoustics	• Lack of sound privacy
16.	O'Brien *et al.* (2012)	• Window shades	• Lighting • Thermal comfort	• Difficulty to operate shades causing solar gain and; • glare
17.	Foster & Oreszczyn (2001)	• Window	• Lighting • Thermal comfort	• Over glazed in most of the buildings (window) causing solar gain and; • glare
18.	Persson *et al.* (2006)	• Window	• Thermal comfort	• Large window glass area contribute to thermal discomfort
19.	Wendt, *et al.*, (2004)	• Envelope tightness	• Indoor Air Quality (IAQ)	• Tight envelope aggravates potential Indoor Air Quality (IAQ).
20.	Paul *et al.* (2010)	• Mechanical ventilation system	• Indoor Air Quality (IAQ)	• Increase dust particle and; • moisture in building
21.	Crump *et al.* (2009)	• Mechanical ventilation system	• Acoustics • Thermal comfort	• Mechanical ventilation system produces noise and; • Cold draught while in operation
22.	Yu & Kim (2012)	• Envelope tightness • Mechanical ventilation system	• Indoor Air Quality (IAQ)	• Ineffectiveness of the ventilation system for removal of VOCs in the indoor environment of the air-tight house
23.	Jensen *et al.* (2005)	• Office layout	• Acoustics	• Noise and; • Lack of sound privacy
24.	Pank *et al.* (2008)	• Envelope tightness	• Thermal comfort	• Air-tightness of the façade cause problems with controlling internal temperatures and; • drafts
25.	Yu *et al.* (2009)	• Air conditioning system	• Indoor Air Quality (IAQ)	• Low indoor air quality pose a threat to human health
26.	Thomsen *et al.* (2005)	• Natural ventilation system • Mechanical ventilation system • Air conditioning system	• Thermal comfort • Acoustics	• Lack of cross ventilation and; • lack of solar shading • mechanically ventilation system cause noise and; • draught problems • Noise caused by heat pump compressor

2.7.2.1 Thermal comfort

According to ASHRAE Standard 55 – 1992: Thermal Environmental Conditions for Human Occupancy, thermal comfort is described as condition of mind, which expresses satisfaction with the thermal environment. Thermal comfort is a subjective matter which is not easily converted into physical parameters because it arises from the body's physiological state and is mainly a sensation from the nerves in the skin (Ampofo *et al.*, 2004). Thermal sensations, satisfaction, and acceptability are all influenced by the match between one's expectations about the indoor climate in a particular context, and what actually exists (Brager & Dear, 2001).

Occupants should be given opportunity to change the indoor climate to suit them well or in other word adaptation to the building's indoor environment. The concept of adaptation to indoor environment was introduced as early as 1936, and formed the basis of a later comparison of field studies of thermal comfort responses in naturally ventilated and mechanically controlled buildings to account for discrepancies in thermal satisfaction (Humphreys, 1976). A study on 160 buildings located on four continents in varied climatic zones by (Dear & Brager, 2002) shows that occupants in naturally ventilated buildings prefer a wider range of indoor temperature that follow the seasonal cycles of the outdoors temperature. The result shows occupants have high tendency to tolerate with the indoor thermal comfort of naturally ventilated buildings.

According to Nicol & Humphreys (2002), the rate of change of comfort temperature in naturally ventilated buildings is greater than in steady conditions of an air conditioned building. More adaptive opportunities the occupants, the more relaxed their thermal environment can be. The rate of change of comfort temperature can be reduced if occupants are allowed to control their indoor environment. Nowadays, thermal comfort research is moving towards achieving "personalized air" through embracing the dynamic and individual nature of comfort (Fanger, 2000). Neutral state of buildings' indoor temperature might not be an ideal approach to mitigate the over consumption of energy in buildings.

The emphasizing of energy-efficient design of a building should not forfeit the importance of indoor environmental quality such as thermal comfort. A study carried out by Aminuddin, Rao & Hong (2012) on energy-efficient buildings in Malaysia shows that occupants were satisfied with their work-spaces, with "slightly greater satisfaction” in the Low Energy Office Building (LEO) than in the Zero Energy Office Building (ZEO) building. Another case study in Malaysia also shows that occupants from natural ventilated building are experiencing long periods of uncomfortable conditions while they are in the building (Mustapha *et al*., 2008). However, a research done by Wang & Wong (2005) in Singapore show that natural ventilation strategy could significantly reduce the thermal impact towards occupants if it was applied adequately and in innovation way to suit building in different climates.

2.7.2.2 Lighting

Lighting has direct impact to human health, behavior, safety, well being, and also productivity. This is because, work performance is highly correlated with the comfort of vision, and high or low intensity of light can influence occupants' motivation while working (Boyce, *et al*., 1989). In a research carried out by Fisk (2001), it is found that there is no substantial evidence to support the idea that improved of lighting quality has high impact towards work performance. However, the improved of occupants satisfaction with lighting control in their work place can improve the suitability of lighting condition in the work place. The intricacy to determine the impact of indoor environment upon productivity is due the fact that to a not too uncomfortable condition will not trigger people attention (Oseland, 1996).

A research conducted by Heschong (2003) shows that there is an inconsistent relationship between horizontal daylight illumination level and productivity. The research findings reveals, higher levels of daylight illumination bring positive impact on attention span and short-term-memory, but not for daily average speed of handling calls. The research also suggests that having a better view out of a window is most consistently associated with better work performance. The practical approach to be applied in energy-efficient buildings are to increase the application of daylight, personal control of lighting levels and improve provisions of views. The integration of energy-efficient technologies can help improve the building performance.

Although the current energy-efficient designs are believe to be able to improve building lighting condition, a research carried out by Lim *et al.* (2012) in Malaysia energy-efficient building shows that light shelf is able to increase daylight distribution uniformity, but failed to reduce glare on vertical plane when direct sunlight patches occurred. According to Lim, Ahmad & Ossen (2012), generally blinds were not a good potential for daylight utilization but good in reducing luminance contrast, integrations of light shelves and partial venetian blind (45° closed) were proposed as the effective designs for all orientations. In order to improve the daylight condition such as building in Malaysia, external shadings is an effective envelope design choice for buildings in the tropic (Ibrahim & Zain-Ahmed, 2007).

2.7.2.3 Indoor Air Quality (IAQ)

ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality, defines acceptable indoor air quality as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities, and with which a substantial majority of people exposed do not express dissatisfaction. According to the Centers for Disease Control and Prevention (CDC), health risks like asthma which is triggered by indoor air quality problems, have increased by 42% between 1982 and 1992 (Wilson & Malin, 1996).

Fisk & Rosenfeld (1998), in their research state that cost of indoor air quality related problems is at $100 billion per year. This incurred cost is due to problems like Sick Building Syndrome (SBS), building related illness, absenteeism, and operation and maintenance cost of problematic buildings. In a review of literature conducted by Seppanen & Fisk (2001) based on eleven studies from six countries in Northern Europe and one from the United States of America, it is found that there is an increase in SBS symptoms associated with mechanically ventilated buildings, though they could not conclude the reasons for such an increase.

A study by Molhave, *et al*. (1993) shows exposure to VOC at low levels in air results in SBS, the effect becomes severe at higher concentrations and in high temperature. A similar research carried out by Wargocki *et al.* (2002) shows removing the pollution source can improve perceived air quality, decrease perceived dryness of air and the severity of headaches, and increase typing performance. Potential health and productivity gains from improved IAQ in building have led to the choices of low VOC materials in the future design of energy-efficient buildings.

. According to Kamaruzzaman & Sabrani (2011), their research's finding shows that in the current situation, the majority of respondents are not satisfied with their office current indoor air quality. This condition is believed to be one of the contributing factors affecting occupants' work productivity and stress level and the energy-efficient designs are able to improve the IAQ of building. A research carried out by Wong & Huang (2004) in Singapore shows that occupants who used air-conditioners while sleeping exhibited one or more SBS symptoms and these occupants usually displayed more SBS symptoms after using air-conditioning than when they utilized natural ventilation. However, there are still a lack of emphasizes on the indoor air quality aspect in the current green buildings development in Malaysia (Elforgani & Rahmat, 2011).

2.7.2.4 Acoustics

Noise from Heating, Ventilation, and Air-Conditioning (HVAC) system, light and other sources can cause discomfort, annoyance and result in headaches and fatigue (Kibert, 2005). Although the current quality of acoustic level in office building might have small health impacts other than inducing fatigue, it has great impact on office worker productivity (Evan & Johnson, 2000). Intelligible noise and lack of speech privacy has a particularly important effect in real life situations in today's office environments (Sundstorm *et al.*, 1994).

In spite of the importance of acoustics quality in buildings, in most cases acoustics doesn't receive the level of design attention as other IEQ criteria (Salter *et al*., 2003). The acoustics quality is important in green buildings, as open plan designs are pervasive for their numerous benefits such as space efficiency, increasing daylight and ventilation penetration, team work, and equality of office space allocation. It becomes important to pay attention to noise and privacy in order not to jeopardize the productivity (Abbaszadeh, 2006).

A research carried out by Rao *et al*. (2012) shows without careful implementation of green building design strategies, acoustic quality is easily compromised, and the research found that building with high energy-efficient has low occupants satisfaction towards it acoustic quality compared to building with slightly less energy-efficient. This could be due to the design strategies implemented to cater for other green building requirements such as the natural ventilation, daylight, reduction of finishes and office layouts unintentionally decrease the acoustical quality (Jalil, *et al.* 2012).

2.8 Building Performance Analysis

BS5240 outlined the term "building performance" and defines it as the behavior of a product in use. It can be used to denote the physical performance characteristics of a building as a whole and of its parts (Clift, 1996). Therefore, it is related to a building's ability to contribute to fulfilling the functions of its intended use (Williams, 1993). Building performance can be evaluated either through inter-building or intra-building ways. Inter-building evaluation is where one building is being compared against another building where clients or occupiers need the comparative analysis of various properties for acquisition or portfolio assessment purposes. On the other hand, intra-building evaluation is assessed on its own without direct reference to other properties. The purpose is to ascertain how well the building is serving the needs of the occupiers or to identify any major deficiencies in its overall performance (Douglas, 1996).

The literature supports the theory that "energy-efficient buildings" have been linked to the quality of indoor environment (Paul & Taylor, 2007). This is one claim about energy-efficient buildings that should undergo evaluation in the near future. In order to substantiate this link, building performance analysis for energy-efficient building should be carried out after completion. Post occupancy evaluation (POE) is no doubt a valuable building performance analysis method which will be further discussed in the following section.

Preiser & Vischer (2005) propose that building performance assessment (analysis) is a process where the actual or expected performance of buildings during the design and construction stage of buildings is systematically compared. This usually involves as annual energy requirements, thermal comfort, embodied energy, cost effectiveness, environmental impact, and other parameters which depend on the purpose of the evaluation (Kordjamshidi, 2011).

According to Douglas (1996), measurability is a key criterion and crucial element to the whole performance concept. However, measurement of performance does not only depend on measurability alone. It also takes factors that are significant and may not yet be measurable into account. The methodologies adopted in the process of evaluation are also significant factors. Understanding the meaning of performance and the leading indicators which provide a measure of defined performance is crucial before starting the performance measurement. This is because, if one cannot measure performance, it cannot be understood nor improved (Williams, 1993).

The ability to define and measure building performance has potentially important long lasting benefits related to the evaluation and valuation of buildings. The outcomes may simply be a protocol to assist in the selection of building for rent, occupation or purchase. The processes also provide an insight in the understanding of how to improve a building to achieve specific performance goals that may be formulated by private companies, public organizations, or governments. As such, the potential benefits of an improved ability to assess building performance must be considered within the current context of many existing awards, benchmarking methods, and performance measurement practices (MacDonald, 2000).

2.8.1 Purpose of building performance analysis

Manning, (1987) states three major purposes for evaluating building performance: (i) to learn how buildings actually perform from existing buildings through their users and the various professionals included. This will provide useful knowledge in the specifications of users-requirements in proposed new buildings; (ii) to assess the possible consequences of design options and their impact on performance. This enhances design effectiveness for future buildings; and (iii) to determine the extent to which the performance of the completed building meet the initial target performance specified in the design stage.

Preiser & Schramn (1997), describes the purpose for building performance evaluation based on four (4) categories, built environment; providers and users; performance level and criteria; and contextual elements (Figure 2.13). (i) Built environment: The elements include workstations, rooms, buildings, and entire complexes of buildings or facilities; (ii) Providers and users: The users or clients could be divided into individuals, groups, and entire organizations; (iii) Performance levels and criteria: The objective of the building performance evaluation varied according to clients goals and user needs, which includes technical (health, safety, security), functional (functionality, efficiency, work flow), behavioral (social, psychological, cultural), and aesthetic performance criteria. (iv) Contextual elements: A good building performance analysis deal with elements such as overall vision as well as historical, political, economic, cultural and other significant elements. The elements are embedded in fourth, which is overarching categories.

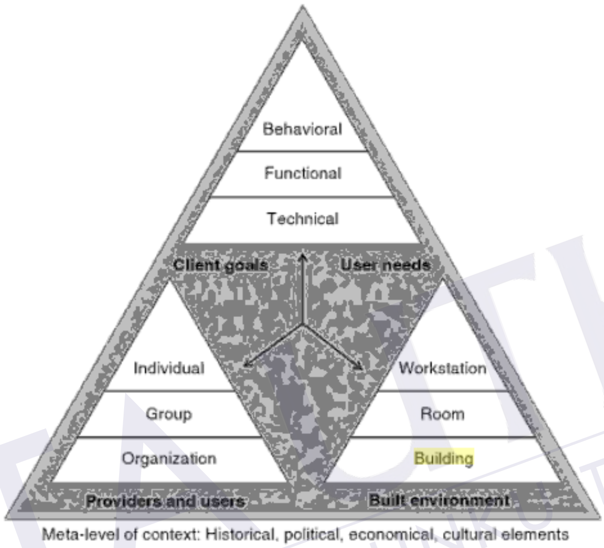

Figure 2.13: Elements and levels of building performance evaluation

2.8.2 Advantages of building performance analysis

The advantages of building performance analysis have increased the acceptance of building performance analysis. The identified benefits are as follow:

(i) Increased objectivity - The performance concept engenders objectivity as opinions are replaced by measures of performance (Hartkopf *et al.*, 1986).

(ii) Clarity of measurement - Measured building performance information and criteria help to clarify the factors that are relevant in the design decision making.

(iii) Advanced professionalism - The expansion of performance information into new areas of knowledge, dissemination and use of performance information in addition to the evaluation and refinement of performance measures and criteria all contribute to professionalism in the building industry (Preiser, 1989).

These advantages are significant to the building industry and the architectural profession. Performance-based products, assemblies, methods and configurations aid the architect in generating building alternatives and design iterations (Preiser, 1989). Preiser (1989) also states that as performance-based measures are used and criteria developed for more building types, the level of professional practice will be improved.

2.9 Building performance analysis method

A review carried out in the 1990s by Baird *et al.* (1996) shows that a large number of techniques have been used for building evaluation. Leaman *et al.* (2010) have categorized the techniques according to their nature and similarity and finally come up with six (6) distinct methods (Figure 2.14), which are usually used during the analysis of building performance.

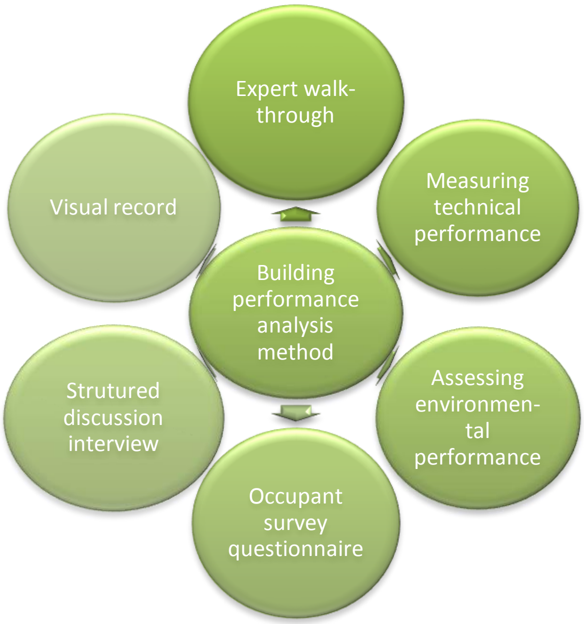

Figure 2.14: Building performance analysis method

(i) Expert walk-through, with informal discussion - This method is quick and most of the time effective; however the authenticity of the experts can be questioned if the information of the experts is not provided in detail. The workability of the method also depends on the researchers' experience, some important information might be left out during the interview session due to immediate responses, comments, or feedbacks are not taken place before the interviewee run out of patience. Therefore, this method is suitable to be carried out by experienced researchers, especially for the initial visit or when uncertainties arise.

(ii) Measuring technical performance - Building fabric, services and systems are the criteria to be measured for their technical performance. Research should be focused on specific criteria and not be side-tracked in order to get the detailed information of the studied building

(iii) Assessing environmental performance - The assessment of building's environmental performance involved energy, water, and indoor air quality. The measurement will usually be carried out with the instrument to gauge the water consumption and indoor air quality. The energy consumption can be gauged through monthly utility bill or using more sophisticated software such as building energy management system.

(iv) Occupant survey questionnaires - People often thought surveys of users as merely subjective. However, according to Gary Raw, users are the best measuring instruments, and they are just harder to calibrate. In order to obtain much precise result, high response rate is required, especially in smaller buildings.

(v) Structured discussions interviews - Structured discussion interviews are needed when the results of occupant and other surveys are available and can form a basis for discussion and identify issues and pin points. Focus groups include a peer group of people can work well in non-domestic buildings. However, in housing, individual interviews are better, as focus groups can easily settle on certain gripes and be dominated by peer pressure.

(vi) Visual record - A visual record of matters are related to the above five points. A photographic record of design features, including videos and thermographic images where appropriate can help highlight features and identify problems.

2.9.1 Justification on the implementation of occupant survey questionnaire

This research focuses on the occupant perspective as the indicator for building performance analysis. Based on the building performance analysis method outlined by Leaman *et al.* (2010), there are two building performance analysis methods involved; occupant survey questionnaire and structured discussions interviews. This section outlines a brief discussion about the selection of occupant survey questionnaire over structured discussion interviews.

In choosing methods, Leaman *et al.* (2010) suggest that the techniques should be relatively inexpensive and not too intrusive or time-consuming. According to Gillham (2007), questionnaire is a low cost survey instrument compared to interview. This is because, extensive training is not required to administer the survey and the processing and analysis are usually simpler and cheaper than other methods. Apart from its low cost advantage, questionnaire survey allows for the collection of a wide diversity of information from a large group of subjects (Smith, Colligan & Tasto, 1979).

It is undeniable that, method such as interview does have its advantages if conducted wisely. Interviewer can clarify the questions if the respondents misunderstood the questions, thus, a relevant response are likely to obtain (Babbie, 1992). However, under certain circumstances, the advantages of the group administered questionnaire may outweigh the benefits of the face to face interview. A research carried out by Job & Bullen (1987) shows that, the group administered questionnaire resulted in greater reliability of the general reaction scale, and more items being supplied in response to an open-ended question regarding disliked features of the working environment. Preskill (1991) has found that questionnaire survey does not only cost-effective yet it is able to provide reliable means for gathering feedback that can be qualitative as well as quantitative.

Long (2006) has summarized some of the advantages of using survey questionnaires over other types of research methods. First, they can be administered to a large population since they do not require individuals from different geographical locations to assemble in one primary place, and thus avoiding considerable cost. Second as opposed to individual interviews survey questionnaires are a non-intrusive means for gathering feedback, as respondents can provide input in a tension or intimidation free environment and at their convenience. Third, biasing, which can easily surface in individual interviews owing to the manner in which questions are posed by the interviewer (sender) and are perceived by the respondent (receiver), is minimized. Finally, completing questionnaires is relatively simple and straightforward and does not require an excessive amount of time.

2.10 Building performance assessment system

There are varieties of assessment systems for buildings used around the world such as, post occupancy evaluation, building in use assessment, building quality assessment, and total building performance (Figure 2.15). Some of the assessment methods are outlined in this section.

Figure 2.15: Types of building performance assessment system

(i) Post occupancy evaluation (POE) - POE is the process of evaluating a building in a systematic and rigorous manner after they had been built and occupied for some time. POE enables building professionals and occupants to gather insights into its occupants' satisfaction level, the building's functionality, environmental performance and in meeting its occupants' other social needs. Such an assessment also gives insights into the consequences of past design decisions and the resulting building performance (Preiser et al., 1988). A more detailed explanation about POE will be discussed in the section 3.0.

(ii) Building in use assessment - Building-In-Use (BIU) assessment is a systematic rather than an analytical approach of yielding information about people and buildings that can be immediately put to use in solving building problems. This assessment approach uses people's experiences of the building tenable to evaluate. It uses occupants' ratings to measure the intrinsic qualities of the environment. The rationale behind this approach is based on the belief that user norms are likely to be more useful as a basis for making decisions about environmental change than ASHRAE or other standards of building performance quality (Vischer, 1989).

(iii) Building quality assessment - Building Quality Assessment (BQA) is a tool for scoring the performance of a building, relating actual performance to identified requirements for user groups in that type of building (Clift, 1996). It is useful in that it provides a first glance overview of the schedule of the building's level of provision. Nine categories that establish a broad classification of users' requirements are used to differentiate the building. These categories are namely: 1) Presentation, 2) Space functionality, 3) Access and circulation, 4) Amenities, 5) Business services, 6) Working environment, 7) Health and safety, 8) Structural and 9) Building Management.

(iv) Total building performance - As the failures in today's office environments are reviewed, the need for a manageable yet comprehensive list of performance mandates for designing or evaluating buildings is imperative (Loftness *et al.*,1989). It is thus critical to begin with a complete definition of the building performance mandates to be assiduously met by building policy makers, consultants, owners, managers etc (Hartkopf *et al*, 1986). This definition can be divided into two parts.

Firstly, there has been a fundamental mandate over centuries for building integrity which is the protection of buildings against environmental degradation and environmental disasters. Secondly, a series of mandates relating to interior occupancy requirements and the elemental parameters of comfort is also relevant. The key conditions for developing this list of performance mandates are that the list be limited in number(fewer than seven), be mutually exclusive and deal holistically with the interdependent human senses (Hartkopf *et al*., 1986).

2.10.1 Justification on the implementation of post occupancy evaluation

Zimring (2002) has summarized some of the advantages of implementing POE and its significance to building analysis: (i) fine-tuning, (ii) diagnosing how to aid a troubled or problematic setting, (iii) deciding whether to expand the scope of an innovative design or technology, (iv) maintaining quality such as by incentives for performance.

(i) Fine-tuning - POE is used as a way of understanding the move-in process and helping reduce problems and misfits. Immediate action could be taken after POE has been carried out, identified problem could be attended to and rectified soon after the evaluation process (Zimring, 2002). Preiser (1995), opines that POE enables owners to "finetuning" the building's facility in order to suit the occupants needs. Survey is required and multiple observations or measurements need to be conducted as to obtain desirable and accurate result.

(ii) POE as diagnosis - POE can help to diagnose the source of problems and prioritize solution if there are complaints or controversy regarding building by the occupants. One of the examples showed by Zimring & Welch (1988) is client dissatisfaction is solved after POE has been conducted, the result shows that the reason causing the offices to be stuffy and hot is due to ductwork that had never been connected by the heating contractors. In this case, the client has successfully identified the problem through POE. In another example, a group of worker from a government office building in Canada has complained about the poor performance of the office building. An in-depth evaluation conducted by Canada commissioned shows that the workers' complaints are justified, the air quality is poor in some locations because of interior partitions that are added after the ventilation system has been designed (Vischer, 1996).

(iii) Using POE to test innovation (identify successful design features to repeat) - Evaluation can help decide whether innovative buildings components should be considered for broader application. According to Watson (2003), organization is able to gain advantages by carrying out POE, and successful design features can be identified through the evaluation process after occupancy. POE is also capable to identify redundant or unnecessary building features; hence, some design flaws could be prevented in the future.

(iv) Maintaining quality - POE is sometimes used to maintain quality control of building, since POE is functioned to compare the current building performance and the desired ones. This is achieved through survey or physical measurement of building. For example, a survey for POE could involve issues such as HVAC, acoustics, odor control, vibration, lighting, fume hood performance, quality of construction or finishes, building appearance and user-friendliness. Through this survey clients are able to identify whether the building perform according to what had planned earlier (Gregerson, 1997).

2.10.2 Elaboration of the post occupancy evaluation (POE) concept applied in the study

The term "POE" originates from the occupancy permit which was issued by building inspectors to confirm that a building was fit for occupancy once completed (Betchel, 1997). The root of POE could be traced back to the 1960s. Although, the term POE was not mentioned by the then researcher, the nature of the research gives some clues about the POE techniques being used at the time was the assessment of building from users' point of view. Evaluation case studies of university dormitories carried out by Sim van der Rijn of the University of California, Berkeley, and Victor Hsia of the

University of Utah are the evidence of the early development of POE (Preiser & Nasar, 2008).

POE in the 1960s involved in individual case studies of public facilities such as hospital and student housing sector/dormitories. The 1970s marked the beginning of the development of POE in more systematic way and with various methods. The rapid transition has increased the use and emphasis on the application of survey, interview, and observation techniques, which mostly focus on housing satisfaction (Akman, 2002). During the mid 1970s the first book on POE was published for the first time authored by Herb McLaughlin of KMD Architecture in San Francisco in the AIA Journal issue of January 1975 (Preiser & Nasar, 2008).

By seeing the logical step and beneficiary results from POE, it was later applied to commercial real estate and office buildings by the mid of 1980s. During 1980s, a lot of large public agencies had established more structured processes to organize information and decisions in their building delivery processes. Agencies such as Public Works Canada and the U.S. Postal Service added building evaluation as a further step in gathering and managing information (Kantrowitz & Farbstein, 1996).

In the recent development, POE has been used to analyze the green building/energy-efficient building performance. Through POE, problems affecting energy-efficient building performance can be easily identified and further reduced the energy consumption of the building caused by the design problem (Sustar, 2007). Birt & Newsham (2009), outlined the usage of POE in the energy-efficient building, and on the average result, acoustics is among the most less satisfaction indoor environmental quality criteria.

2.10.2.1 Definition

POEs are conducted by a wide range of practitioners for many different purposes, and there is no common definition (Zimring, 2002). Therefore, in this section, the various definition of POE from previous studies will be gathered and a definition will be derived from the literature study.

POE is a tool to account for building quality. It is essential when organizations are required to demonstrate that building programs are being responsibly managed (Watson, 2003). Zimring & Reizenstein (1980) defined POE as examination of the effectiveness for human users of occupied design environments. According to Zimmerman & Martin (2010), typically, POE focuses on assessment of client satisfaction and functional “fit” with a specific space, the criteria for judgment are the fulfillment of the functional program and the occupants’ needs.

US Federal Facilities Council (2002) denotes that POE is a process of systematically evaluating the performance of buildings after they have been built and occupied for some time. Preiser (2002) suggests that POE could be defined as a process of systematic data collection, analysis, and comparison with explicitly stated performance criteria pertaining to occupied built environments. Friedmann *et al*. (1978) argue that POE is an appraisal of the degree to which a designed setting satisfies and supports explicit and implicitly human needs and values of those for whom a building is designed.

Khalil & Husin (2009), state that, POE is a prominent tool that is able to indicate satisfaction and comfort level needs by building occupants as lesson learned to identify problems in indoor environment. Vischer (2002), defines POE as any and all activities that originate out of an interest in learning how a building performs once it is built, including if and how well it has met expectation. Royal Institute of British Architects (RIBA) Research Steering Group (RIBA, 1991) defines POE as a systematic study of building in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have.

According to Meir *et al.* (2009), POE is a platform for the systematic study of buildings once occupied, so that lessons may be learned that will improve their current conditions and guide the design of future buildings. Another definition by Preiser (1995) states that POE is a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically. In general, the definition of POE could be concluded under the definition by Weiss (1997) states that, POE is the systematic assessment of the process of delivering buildings or other designed settings or of the performance of those settings as they are actually used, or both, as compared to set of implicit or explicit standards, with the intention of improving the process or settings.

2.11 Summary

Energy-efficient building is a practical solution for the current environmental problems caused by ever increasing energy consumed by buildings. The sophisticated design for energy-efficient buildings can undoubtedly increase buildings' efficiency in terms of its energy performance. However, architects, designers and buildings' owner should not overlook the importance of buildings' indoor environment performance of high energy efficiency building. Attention should not only given to the indoor environmental quality measurement, occupants could be a precise indicator for the indoor environmental performance. Since human is the end user of the building, each deficiency of the building design will directly impact the occupants. Post occupancy assessment on building is crucial to gauge the real performance of buildings during occupancy stage. With the presence of human in the building, the interaction between users and building environment can provide important information about the current performance of building. In the next chapter, the methodology applied in this research will be discussed in detailed where a comprehensive research methodology is pivotal factor to achieve research objectives and aims.

CHAPTER 3

RESEARCH METHODOLOGY

Research Methodology is an important part in executing an academic research. The purpose of research methodology is to organize the research mechanism as the research can be carried out smoothly and effectively. Hence, research methodology can be considered as a systematic framework based on sequences and aimed to achieve the research objectives. Overall, the procedures to carry out the research methodology can be summarized as follows.

Phase 1

- Preliminary study
- Literature review
- Data Collection

Phase 2

- Survey Framework Development
- Content Validity Test
- Exploratory Factor Analysis
- Pilot Study

Phase 3

- Preliminary study
- Survey Framework Testing
- Data analysis
- Conclusion and recommendation

3.1 Introduction

The impacts of the ever increasing energy consumption have drawn attention from various parties over the past decades. This is because the over consumption of fossil energy could lead to the increase of greenhouse gasses emission and thus can bring to major environmental destruction. Besides that, the high demand for fossil energy also causes its price to increase in recent years. Thus, many countries are started to seek for alternative energy and promote reducing energy consumption in various means.

The development of energy-efficient building sectors in Malaysia is not new compared to other countries in the region. In fact, Malaysia has started its renewable energy developments since a few decades ago. The development of three showcase energy-efficient buildings is the pioneer projects initiated by the government. The buildings are known as Ministry of Energy, Communications, and Multimedia office building, Energy Commission office building, and Malaysia Green Technology Corporation office building. These three showcase buildings have set a benchmark for the future development of energy-efficient building projects. Therefore, to maintain the performance of buildings should be a priority for the owner and the buildings' designer team. However, building performance issues during occupancy stage has never an easy task for owners and especially the design team. Hence, this research will critically study the building performance issues during occupancy stage by studying the occupants' perception towards building performance. The literature review from previous studies shows the relationship between occupant satisfaction and building's Indoor Environmental Quality (IEQ) can be positively correlated with better building performance. Post Occupancy Evaluation is an important process to assess the building performance after occupancy.

In order to achieve the research aim and objectives, a research methodology has been constructed. This research was carried out in two phases; the first phase involves preliminary study, literature review, data collection, data analysis, and evaluation framework development. After the completion of the first phase, the second phase of the research was beginning with the preliminary study, data collection, data analysis, and lastly conclusion, and recommendation. The flow chart of the research methodology is shown in Figure 3.1. The following section of this chapter will discuss in detail about each phase of the research methodology.

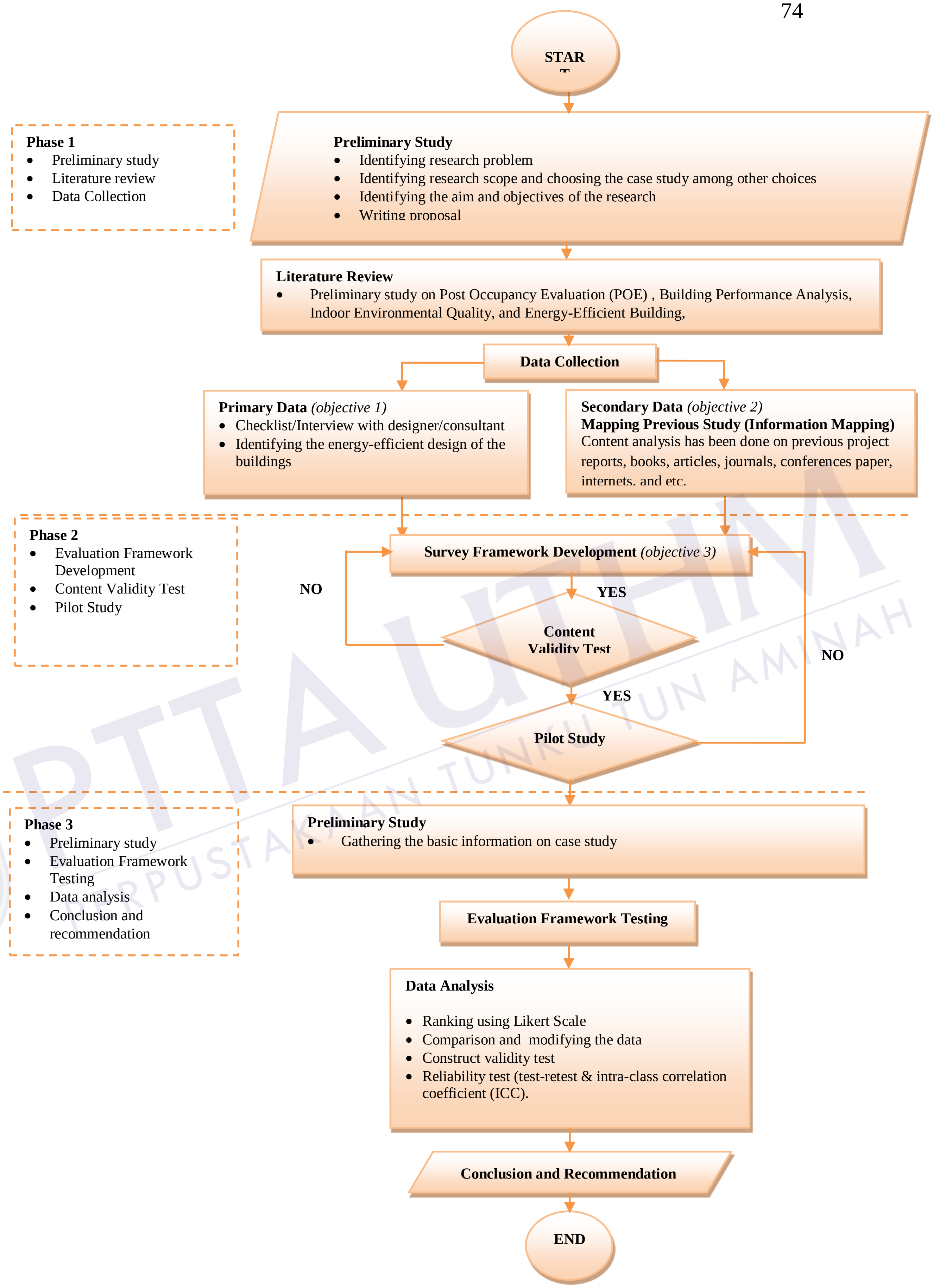

Figure 3.1: Flow chart of research methodology

3.2 Preliminary study

At the beginning of the research, research problems were identified. This is important because by identifying the research problems, aims and objectives of the research can be further outlined through the research gap of the research problems. Research scopes were formed and case studies of the research were chosen as well. The selection of case studies was based on the availability of areas of study that match the aim and objectives in this research.

3.3 Case study building

Table 3.1: Energy-efficient building in Malaysia (GBI, 2012)

Buildings	Recognition/certification	Building operation status
Ministry of Energy, Communications, and Multimedia office building	2006 ASEAN building energy awards	- Completed - Building operation: <than 1 year
Green Energy Office (GEO)	GBI Certified	- Completed - Building operation: <than 1 year
ST Diamond Building	GBI Platinum, Green Mark Platinum	- Completed - Building operation: <than 1 year
Shell IT Centre	LEED Gold	- Completed - Building operation: <than 1 year
Kompleks Kerja Raya 2 (KKR2)	GBI Platinum	Under Construction
Mercu Mustapha Kamal	GBI Gold	Under Construction
348 Sentral Shell Malaysia	LEED Gold	Under Construction
Public Mutual Bank Headquarter	GBI Gold, LEED Gold	Under Construction
Sarawak Energy Headquarter	GBI Certified	Under Construction
Sunpower PV Manufacturing Plant	LEED Platinum	Under Construction
OLC Integrated Development , KLCC	GBI Gold, LEED Gold	Under Construction
Menara Worldwide	GBI Certified	- Completed - Building operation > than 1 year
Menara 1 First Avenue, Bandar Utama	GBI Gold	- Completed - Building operation > than 1 year
Menara Binjai	GBI Certified	Under Construction
Summer Suites/Menara Solaris KLCC	Green Mark	Under Construction
DIGI Technology Operation Centre	GBI Gold	- Completed - Building operation > than 1 year
Menara Felda	GBI Certified	Under Construction

The sample of the buildings for the research were determined based on these criteria: the buildings have been certified by the sustainability building rating tools such as Green Building Index (GBI), Leadership in Energy and Environmental Design (LEED), and GreenMark or have obtained green building energy awards. These buildings also have energy-efficient design architecture features. The samplings obtained are shown in Table 3.1. The selection of the buildings from the sampling was based on the building occupancy period exceeding one year after move in. According to Zagreus *et al.* (2004), the best time to carry out POE is one year after occupancy. This is to ensure that an acceptable interval elapsed between the move and the POE survey. Hence, the EEBEQ survey has been tested at three (3) showcase energy-efficient building in Malaysia: Ministry of Energy, Communications, and Multimedia office building and Energy Commission office building which are situated in Putrajaya, and Malaysia Green Technology Corporation office building located is in Bandar Baru Bangi. The three energy-efficient buildings also have been rated as the most energy-efficient building in Malaysia and set as national benchmark or showcase building for energy-efficient buildings.

3.4 Literature review

Literature study is the information or data obtained before the research is being carried out, and the information is based on the previous research conducted by researchers. In addition, literature study is aimed to achieve the background of the research topic and obtain a suitable research methodology. The information gathered during literature study can further strengthen the research that will be executed. The information gathering of the Indoor Environmental Quality (IEQ), building performance analysis, energy-efficient building and Post Occupancy Evaluation (POE) will contribute to better understanding of the background of research and the data collection of previous researches were used to construct the evaluation framework.

3.5 Data collection

Data collection method in this research can be categorized into primary data and secondary data. Primary data is the main data collected in the research. Whereas, secondary data is the data retrieved from previous studies.

3.5.1 Primary data

Primary data is the information gathered from an empirical study. The methods applied in this research are interview and observation.

3.5.1.2 Interview

Interview is an approach used to collect information or data from respondents through verbal communication. The reply from the interviewee could be in the form of perception or advice. The advantage of this method is the interviewers have more time to explain his questions in detailed. Interview also allows two ways communication between the interviewer and interviewee. This could contribute to the formation of different perspective. The interview questions in this research were based on semi-structural style, where the interview sessions were conducted in partially formal. Besides that, the questions for interview could be rearranged during the interview session due to the flexibility of the questions' structure. Questions could be added or reduced according to the subject topics.

3.5.1.3 Observation

Photos were taken during the visit to case study buildings, energy-efficient design components applied in the building design were identified based on the explanation given by the building management team. The identified design components are passive and active system applied in the case study building.

3.5.2 Secondary data

Secondary data is data obtained from literature review. It can be divided into primary source and secondary source. The information gathered from this research was from primary and secondary source. Primary source is used to solidify the idea or information which obtained from previous study, for example, journal, article, and abstract. Secondary source is able to provide a bigger picture of the problems of studied topic. Examples of secondary source include books and encyclopedia. The latest information could be retrieved from the internet searching. Apart from that, the services of library such as latest subscription with online portal could also be the source of the information gathered.

3.5.3 Mapping of previous studies

In this stage, the IEQ criteria and energy-efficient design parameter were identified. This is a continuing process from the literature review. Only the suitable energy-efficient parameters and IEQ criteria were selected based on the mapping process from previous studies. The detailed of the analysis will be discussed in chapter 4.

3.6 Construct initial questionnaire templates

The information gathered from the mapping of previous studies procedure was used to formulate the initial evaluation framework template. The contents of the evaluation were divided into two sections: Section A: General information of the respondent; Section B: Indoor environmental quality. After the formulation of initial evaluation framework template, the evaluation framework was going through content validation procedure and pilot test.

3.6.1 Content validity test

The content validity test is a tool to assess the validation and correctness of the evaluation framework contents. This process is important to determine the questions asked in the evaluation framework are reliable and capable of achieving the research objectives. The content validity of this research was tested by referring to the energy consultants, energy management consultant, project officer, and architects. These are the key people involved in the construction and design of the case study buildings. They were asked to fill in a form and state whether the questions in the evaluation framework are highly relevant, moderately relevant or lowly relevant. The data from the validity test were analyzed using Lawshe Method of content validation. According to the Lawshe Method, a minimum of 5 panelists should be chosen for validation test (Lawshe, 1975). The result from the expert panelists needs to display a high consensus on the validity with Content Validity Ratio (CVR) 0.99. The consensus among panelists on the necessity to include a specific component can be quantified by determining the content validity ratio (CVR). The following formula is used for this purpose.

$$CVR = (n_e - n/2)/(n/2)$$

n_e = number of panelists indicating "essential"
n/2 = number of panelists divided by two
CVR = direct linear transformation from the panelists saying "essential"

3.6.2 Pilot study

Pilot study was conducted right before the evaluation framework has been finalized. It is a small scale of preliminary study performed before the finalized evaluation frameworks are distributed (Polit *et al.*, 2001). The main purpose of the pilot study is to check the feasibility or to improve the design of the research tools. Pilot study is important to evaluate the efficiency and adequacy of the sampling. According to Neuman (1997), a "small set of respondents" are needed for pilot test. Hence, in this study 10-20% of the sample size for actual study of the studied building was selected for pilot study.

3.7 Survey framework testing

The finalized survey framework Energy-efficient Building Environmental Quality Evaluation Framework (EEBEQ) was then tested in three energy-efficient building. The EEBEQ testing was conducted in the case study buildings identified during the phase 1 of the research. After retrieving the feedback from the respondents, the data were analyzed using SPSS software in order to allow credible inferences to be drawn from the data provided. The incomplete EEBEQ are not be used for analysis purposes. The sample size and sampling data analysis will be discussed in the following subtopics.

3.7.1 Sampling

The sample size of the research was randomly selected from each studied building. After the population of the occupants in each building has been determined, the 30% of the size of the sample was selected, According to Fellows & Liu (2003), the normal expected useable response rate is ranging from 25% to 35%. Therefore, the 30% of the sample size is sufficient enough to provide reliable result data.

3.7.2 Sampling data analysis

The result from the testing process was validated based on sociological principles and test procedures for validation. From sociological point of view, the validation process is important as good validity presupposes good reliability, but the reliability can be good although the validity is bad (Engvall *et al.*, 2003)

3.7.2.1 Reliability

The reliability tests performed in this research were Croanbach α coefficient and intra-class correlation coefficient (ICC). The Cronbach α is a measure of the inner consistency. According to Li & Wang (2007), Cronbach α between 1.3 and 0.7 shows high reliability. Hence, if Cronbach α is less than 0.3, reliability is in low level and cannot be accepted. If Cronbach α is greater than 0.7, this reveal that consistency is on a high level and is acceptable. Intra-class correlation coefficient (ICC) is used to analyze the reliability of an instrument. In this research, it is hypothesized that occupants in the same building would report relatively small variations in the EEBEQ subscales as compared to much larger variations reported between buildings. Hence, the ICC was used to assess the total variance of the subscales between building variance, where, the higher the degree of consensus between occupants in same building shows greater reliability (Chan *et al.*, 2010). ICC value of less than 0.40 indicates poor reliability; ICC values in the range 0.40 to 0.75 indicate fair to good reliability, and an ICC value of greater than 0.75 shows excellent reliability (Sampat *et al.*, 2006).

3.7.2.2 Validity

This research involves three types of validation process; content validation, criterion validation and construct validation. Content validation was performed during the phase 2 of the research. Meanwhile the criterion and construct validation were performed in phase 3 after the evaluation framework has been tested. This process is important to determine whether the EEBEQ assessed the criteria it intends to achieve during the design process.

(a) Criterion validity

Criterion validity is to measure an instrument as to accurately predict behavior or ability in a given area (Jackson, 2009). In this research, criterion validity was carried out by comparing the EEBEQ result with the similar Indoor Environmental Quality

(IEQ) survey instrument, Building Use Studies (BUS). The BUS was chosen due to its usage for more than ten years in gathering data on occupied office building. The wide usage of BUS has proved the instrument validity (McDougall, *et al.* 2002). The IEQ criteria in EEBEQ and BUS are compared and correlated. The high correlation between each criterion shows greater validity of the EEBEQ survey instrument.

(b) Construct validity

According to Jackson (2009), construct validity is a test that assesses the extent to which a measuring instrument accurately measures a theoretical construct or trait it is designed to measure. As suggested by Kumar (2005), a question from BUS evaluation framework in regard to overall satisfaction of IEQ comfort was used to compare with the sum of the IEQ criteria from EEBEQ, the higher the correlation between each two shows higher validity of the instrument.

3.7.3 Pearson correlation coefficient

The Pearson correlation coefficient was used to assess the criterion and construct validity of the EEBEQ evaluation framework. Pearson Correlation is the most common measure of correlation in statistics as it shows the linear relationship between two variables (Bolboacă & Jantschi, 2006). The formula of Pearson Correlation Coefficient is shown as below:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

r (rho) is the correlation coefficient for the sample, *r* at the value of -1.0 is a perfect negative (inverse) correlation, 0.0 is no correlation, and 1.0 is a perfect positive correlation. To assess the statistical significance of the correlation, p-value is needed to calculate alongside the Pearson coefficient, which can be interpreted as follows:

(a) If the p-value is low (generally less than 0.05), then the correlation is statistically significant.

(b) If the p-value is not low (generally higher than 0.05), then the correlation is not statistically significant

Hence, in the final calculation of correlation, variables are correlated if the Pearson correlation is less than 0.05.

3.7.3.1 P-value

The procedure to obtain the p-value as suggested shows as below (Life sciences, 2012):

Table 3.3: Pearson's correlation coefficient *r* (Critical Values)

	Level of Significance for a One-Tailed Test										
	.05	.025	.01	.005	.0005		.05	.025	.01	.005	.0005
	Level of Significance for a Two-Tailed Test										
df=(N-2)	.10	.05	.02	.01	.001	*df*=(N-2)	.10	.05	.02	.01	.001
1	0.988	0.997	0.9995	0.9999	0.99999	21	0.352	0.413	0.482	0.526	0.640
2	0.900	0.950	0.980	0.990	0.999	22	0.344	0.404	0.472	0.515	0.629
3	0.805	0.878	0.934	0.959	0.991	23	0.337	0.396	0.462	0.505	0.618
4	0.729	0.811	0.882	0.971	0.974	24	0.330	0.388	0.453	0.496	0.607
5	0.669	0.755	0.833	0.875	0.951	25	0.323	0.381	0.445	0.487	0.597
6	0.621	0.707	0.789	0.834	0.928	26	0.317	0.374	0.437	0.479	0.588
7	0.582	0.666	0.750	0.798	0.898	27	0.311	0.367	0.430	0.471	0.579
8	0.549	0.632	0.715	0.765	0.872	28	0.306	0.361	0.423	0.463	0.570
9	0.521	0.602	0.685	0.735	0.847	29	0.301	0.355	0.416	0.456	0.562
10	0.497	0.576	0.658	0.708	0.823	30	0.296	0.349	0.409	0.449	0.554
11	0.476	0.553	0.634	0.684	0.801	40	0.257	0.304	0.358	0.393	0.490
12	0.457	0.532	0.612	0.661	0.780	60	0.211	0.250	0.295	0.325	0.408
13	0.441	0.514	0.592	0.641	0.760	120	0.150	0.178	0.210	0.232	0.294
14	0.426	0.497	0.574	0.623	0.742	∞	0.073	0.087	0.103	0.114	0.146
15	0.412	0.482	0.558	0.606	0.725						
16	0.400	0.468	0.542	0.590	0.708						
17	0.389	0.456	0.529	0.575	0.693						
18	0.378	0.444	0.515	0.561	0.679						
19	0.369	0.433	0.503	0.549	0.665						
20	0.360	0.423	0.492	0.537	0.652						

i. Decide a One-Tailed or Two-Tailed Test

   (a) One-Tail: have an a priori: hypothesis as to the sign (- or +) of the correlation.

   (b) Two-Tail: no priori: hypothesis as to the sign of the correlation.

ii. Calculate df (degrees of freedom) = N (sample size) - 2).

iii. Locate this df in the table.

iv. Use this row of threshold values.

v. Read across this row from left to right until find a value greater than the calculated r statistic.

vi. The P–value for the observation is the P–value at the top of the first column to the left of the value.

vii. A $P < 0.05$ (or smaller) value indicates that the null hypothesis can be rejected and the two variables are not correlated. In other words, there is evidence the variables are significantly related. If r statistic value lies to the left of the 0.05 column, then the results are not significant ($P > 0.05$). Null hypothesis cannot be rejected and the variables are unrelated.

3.8 Summary

The methodology for the research has been outlined in this chapter. The procedures for the methodology were divided into 3 phases. First phase involves preliminary study, literature review, and data collection. The aims and objectives of the research were determined through the identification of problem statements. Literature review is needed for gathering information from previous research, and the information gathered during literature review was incorporated into the data collection procedures. Data collection in this research was conducted through primary and secondary data collection approach. Primary data was gathered through interview and observation on case study buildings, while secondary data were gathered through the mapping of previous studies. After the completion of data collection, phase 2 of the research begin with survey framework development. In this phase, EEBEQ was formed and content validation was carried out in order to determine the validity of the EEBEQ content. The 5 experts involved in the energy-efficient building industry were indentified and their opinions were gathered for the content validation. Pilot test is carried out after the EEBEQ content has been validated. Phase 3 is starts right after the completion of the pilot study. The structure of the evaluation framework was further simplified after the pilot study and from the feedback given by industry’s expertise. The modified EEBEQ was tested on the case study building; the reliability and validity of the EEBEQ were analyzed through the sociological validation process such as criterion validity, construct validity, intra-class correlation (ICC) and exploratory factor analysis. A comprehensive research methodology is an important factor for a research process. This research was carried out based on the discussed research methodology procedures. The collection of the data will be discussed in the following chapter.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

Data collection of the research was conducted through methods such as interview, observation, mapping of previous studies and sociological validation process. Interview sessions were carried out with the key peoples of the buildings; architects, consultants, and building management team with the aim to identify the energy-efficient components and the passive design applied in the buildings. This process had been carried out along with the observation or site visits to the case study buildings; Malaysia Green Technology Corporation, Energy Commission, and Ministry of Energy, Green Technology and Water. Photos were taken in order to identify the energy-efficient design of the buildings.

The information regarding energy-efficient design affecting the building Indoor Environmental Quality (IEQ) have been identified. Each of the information gathered from previous studies were then arranged and mapped based on the IEQ criteria and energy efficient design components. This process is aimed to identify the energy-efficient design problems which affect occupants' comfort in terms of IEQ. EEBEQ was formed based on the information gathered through interview, observation and mapping of previous studies process. The newly constructed EEBEQ has gone through a series of sociological validation processes which involved criterion validity, construct validity and intra-class correlation (ICC). In this chapter the information obtained from each method as mentioned above are analyzed and discussed in detail.

4.2 Interviewees' background

In this research the interviewees were chosen among the key peoples who had been previously involved in the development of energy-efficient buildings. The information gathered through this process is important for identification of the energy-efficient components and the passive design applied in the case study buildings.

Respondent A is the energy, operation and maintenance consultant for Malaysia Green Technology Corporation. He has been involved in the development of one of the energy-efficient buildings, which is the office building of Malaysia Green Technology Corporation. Respondent B is the project official involved during the preliminary, design, and construction stage of Malaysia Green Technology Corporation building. Currently he is responsible for the operation and maintenance of the office building.

Respondent C is an engineer from IEN Consultants Sdn. Bhd. He is one of the energy consultants involved in the design stage of Malaysia Green Technology Corporation. Respondent D is an architect from Ruslan Khalid Associates Sdn, Bhd. He is the architect who took part in the design process of the energy-efficient building.

4.2.1 Information coding

The information gathered from the interview session was transformed into matrix table format as shown in Table 4.1. The information is divided into two main criteria; passive design, and energy-efficient components. The details of each energy-efficient design identify through interview and observations will be further discussed in the following subtopic after the completion of information coding process. The purpose of this process is to identify the energy-efficient design in the case study buildings. This is because energy-efficient buildings vary in terms of their design based on the climatic condition where the building is situated. Hence, it is important to identify the energy-efficient designs in the case study buildings which are situated in a hot and humid climatic country - Malaysia. The information coding and data collection from previous researches regarding energy-efficient design problems which are affecting occupants' comfort were conducted based on the design details identified in the interview and observation process

Table 4.1: Information coding table

Design criteria	Design detailed
Passive design	• Building orientation • Insulation system (external wall/internal wall/roof) • Daylighting • Skylight • Daylight source from atrium roof • Daylight source from the side of the building • Internal layout • Double glazing window • Shading • Reduced internal load
Energy-efficient design components	• Cooling system • Trickling cool roof • Cooling tower • Rainwater collection • Phase change material (PCM) • Variable air volume (VAV) • Variable speed drive (VSD) • Chilled slab • Chilled metal ceiling • Energy-efficient lighting system

4.3 Energy-efficient and passive design components

The information gathered from the interview and observation process found that the main components of passive design and energy-efficient designs applied in the case study buildings are building orientation, daylighting, insulation system, air-conditioning system, and energy-efficient lighting system. The details of each component will be discussed in the following subtopics.

4.3.1 Building orientation

The orientation of the office building is in the north-south axis orientation, where the building walls that have large surface area are designed to be located perpendicular to the north-south axis, while the building walls that have small surface area are designed to be located parallel to the east-west axis as shown in Figure 4.1. The goal of this approach is to maximize the daylighting of the building and reduce the thermal impact.

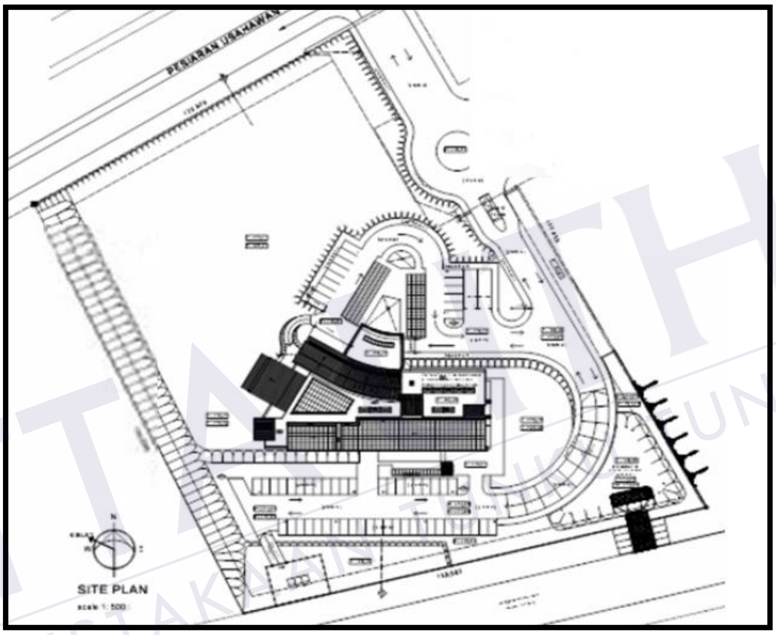

Figure 4.1: Site plan of Malaysia Green Technology Corporation building

The purpose of the building orientation is to reduce the amount of direct sunlight from the building large surface area. This is because large amount of direct sunlight can increase the building indoor temperature. Figure 4.2 shows the east-west axis of the case study building. Based on Figure 4.2, the building walls facing east and west are designed with less windows feature and small surface area in order to reduce the direct sunlight effect on building. Figure 4.3 shows the building wall facing the south and north direction. These parts of building wall are designed with large surface area and a lot of window features. The purpose of this design is to increase the diffuse light effect to the building in order to reduce the artificial lighting usage in this building area.

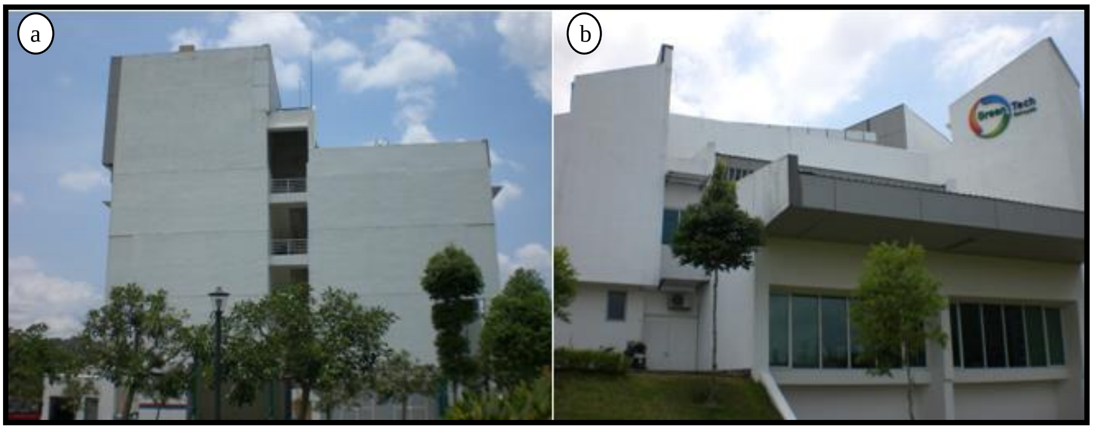

Figure 4.2: (a) Building wall facing east (b) Building wall facing west

Figure 4.3: (a) Building wall facing north (b) Building wall facing south

4.3.2 Daylighting

Daylighting applied in the case studies building include daylight source from the top of the building, and daylight source from the side of the building. To improve the daylighting performance, building layout, window glass material, and window shades are the important components in building emphasized on daylighting design.

4.3.2.1 Daylight source from the top of the building

The daylight source from the top of the building is the source of light from the roof and the atrium with Building Integrated Photovoltaic (BIPV) panel functioning as a roof.

(a) Sunlight source from rooftop (skylight)

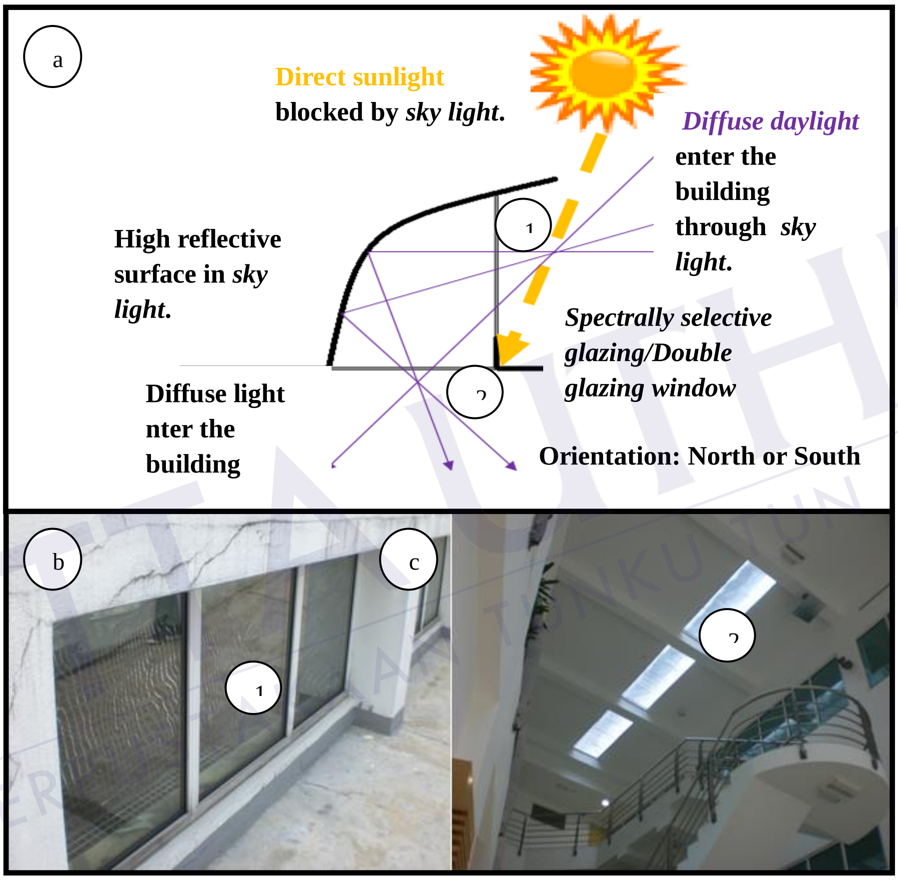

Figure 4.4: (a) The process of diffused light entering the building through skylight (b) Spectrally selective glazing (c) Natural sunlight from rooftop

Figure 4.4 shows the process of diffused light entering the building through skylight. The figure shows that direct sunlight is blocked by skylights, and only the diffused light is permitted to admit through the skylight by passing through spectral selective glazing/double glazing window and then the diffused light is reflected into the building. This is the indirect method using reflection and refraction of the sunlight.

(b) Sunlight source from atrium roof

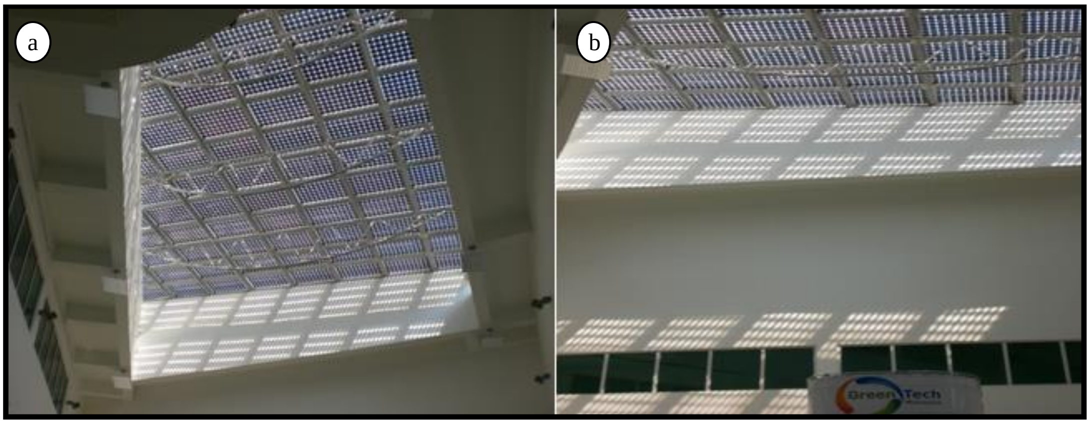

Figure 4.5: (a) & (b) Sunlight entering the building through Building Integrated Photovoltaic (BIPV) panel functioning as atrium roof of the building

Light source from PV panels acts as atrium roof allowing daylight to enter the building through PV panel as shown in Figure 4.5.

4.3.2.1 Daylight source from the side of the building

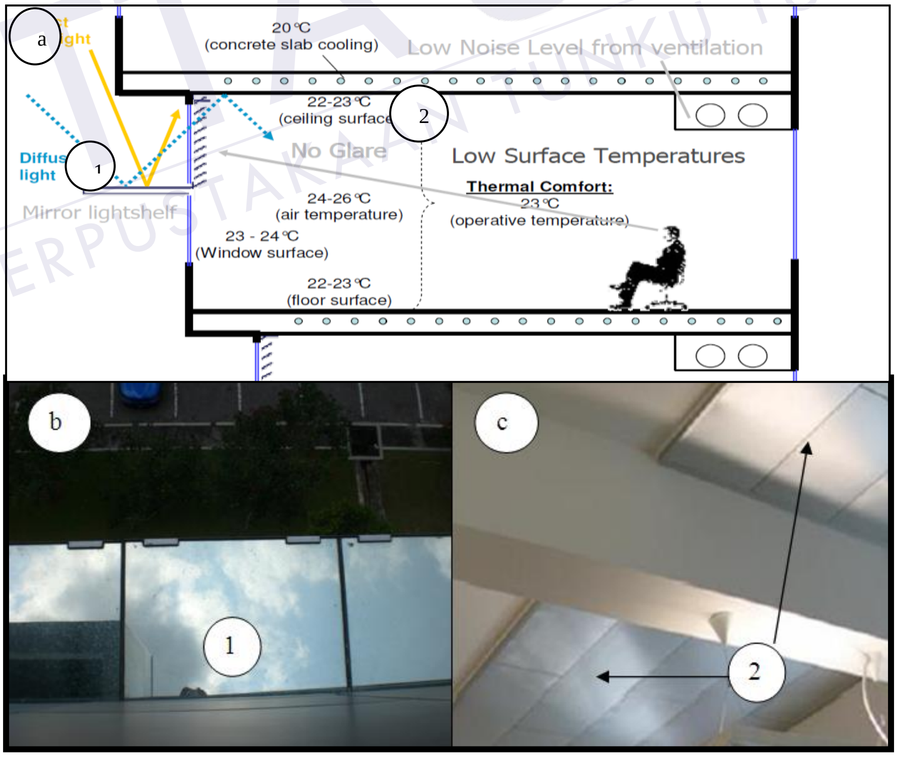

Figure 4.6: (a) Diffused light entering the building (b) Mirror lightshelf (c) High reflective ceiling

In order to optimize the diffused light intensity in the building, wall perpendicular to the diffuse light source are designed in transparent as shown in Figure 4.7. Besides that the interior design of the building is applied with bright color, with the purpose to allow more lights to enter the building surrounding.

Figure 4.7: (a) Transparent wall (b) Window area

4.3.2.3 Building internal layout

The workplace is placed near to the window area so that daylights are permitted to enter the workplace area thoroughly, while the storage room is placed in the area which has fewer window features as shown in Figure 4.8.

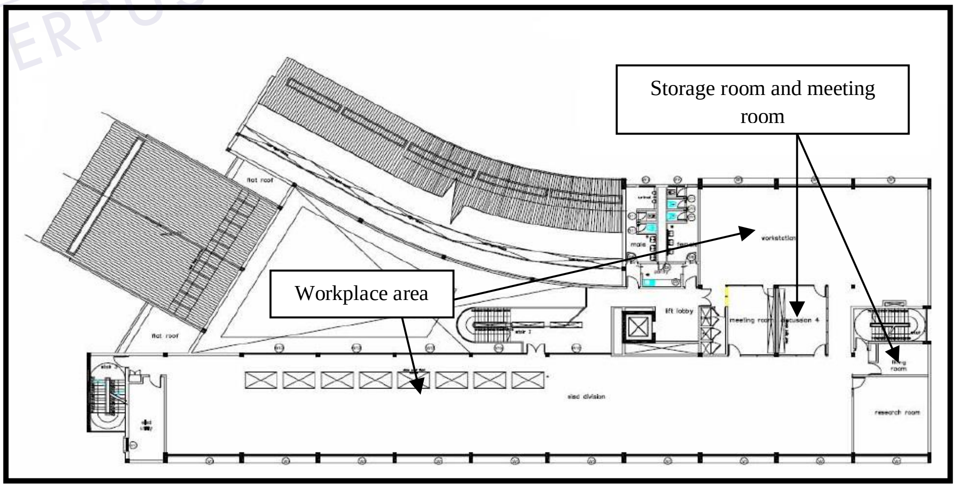

Figure 4.8: Internal layout of energy-efficient building

4.3.2.4 Window glass

The type of window glass used in Malaysia Green Technology Corporation is double glazing as shown in Figure 4.9.

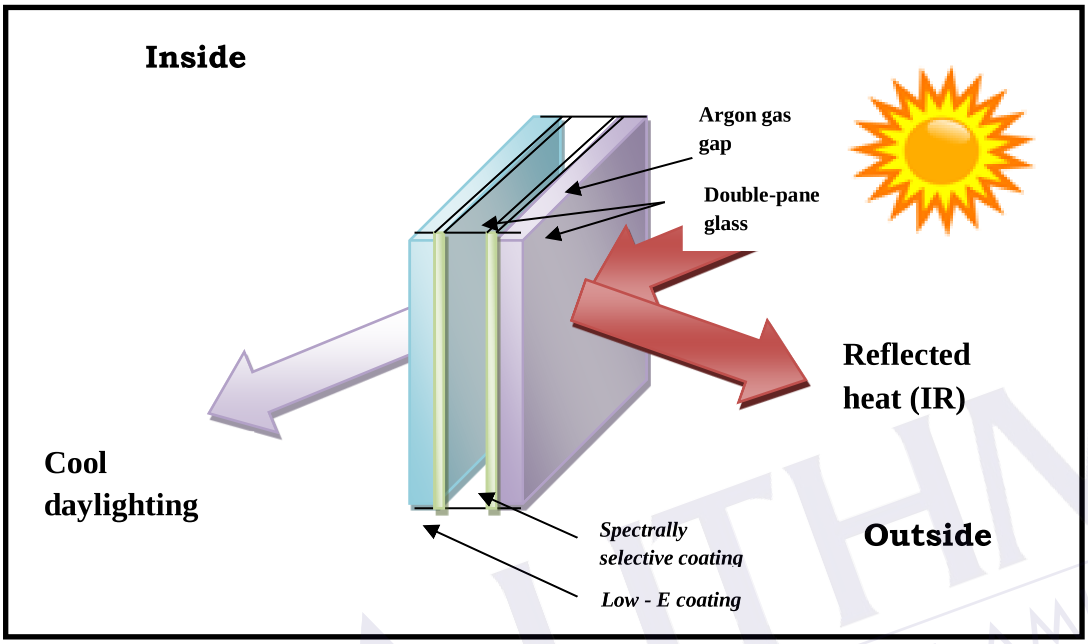

Figure 4.9: Schematic diagram of double glazing window

Based on Figure 4.9, double glazing window shows the capability to reflect heat out of the building and only allow diffused light to enter the building. Argon gas gap in between the window glass gives it high reflective characteristics and makes it able to reflect infrared and ultraviolet light. The thickness of double glazing window in the Malaysia Green Technology Corporation is 12 mm, with 63.1 percent visible transmittance and 0.57 shading coefficient (SC) value.

4.3.2.5 Shading

Shading plate, louver, and step-in design are the approaches used in Malaysia Green Technology Corporation in reducing the direct sunlight effect.

(a) Shading plate

Shading plates as shown in Figure 4.10 act as barricade shield to shield the excessive sunlight from entering the building. The shading plate is designed with features such as mirror lightshelve, where mirror is installed on the upper side of the shading plate in order to reflect the diffuse light into the building.

Figure 4.10: Shading plate

(b) Louvers

Louvers as shown in Figure 4.11 function as filters to eliminate the excessive sunlight from entering the building. The louvers installed in the double glazing window are in white color on the inside and specular reflective on the outside. The purpose is to reflect the direct sunlight out of the building and allow the diffuse light to enter the building.

Figure 4.11: Louvers

(c) Step-in design (self-shading)

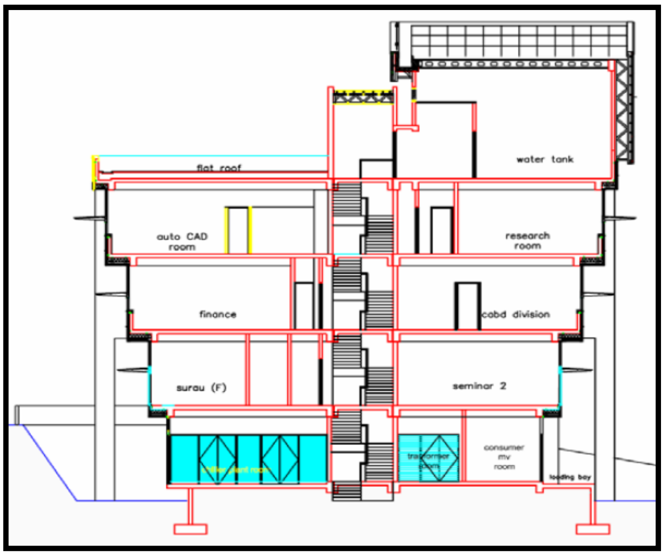

Figure 4.12: Step-in design (self-shading)

Step-in design is an approach applied in tall buildings. This is because, tall building has high structure feature, and designers can apply such feature to benefit the thermal reduction in the building. The tall feature of the building can act as shading to the building itself.

4.3.3 Insulation system

The insulation system at Malaysia Green Technology Corporation office building was installed in the internal wall, external wall and roofing. The purpose is to function as heat insulator and reduce the transfer of heat from outside of building through building envelope.

(a) Internal wall

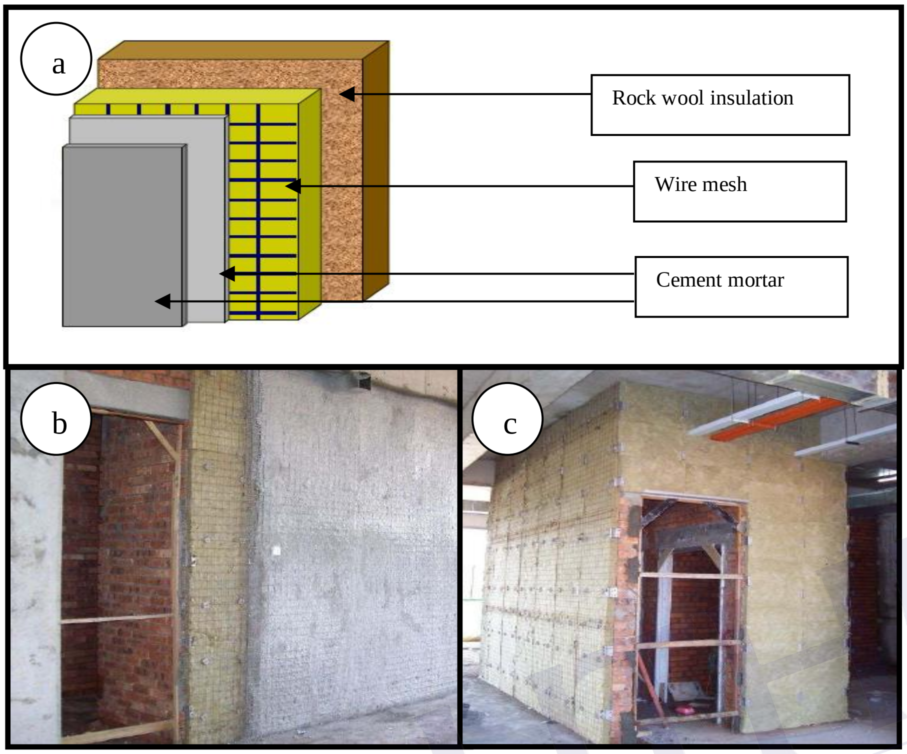

Figure 4.13: (a) Office building internal wall (b) & (c) Internal wall installed with insulation system during construction of the building

The internal walls are installed with a layer of rock wool insulation as shown in Figure 4.13, in order to reduce thermal effects in the office building. 50 mm thick rock wool was installed in the internal wall and with 0.84w/m^{2}k thermal performance.

(b) External wall

The external walls are installed with two layers of rock wool insulation as shown in Figure 4.14, because it receives greater thermal effects compared to internal walls. The rock wools installed in the external wall are thicker than the rock wool installed in internal wall.

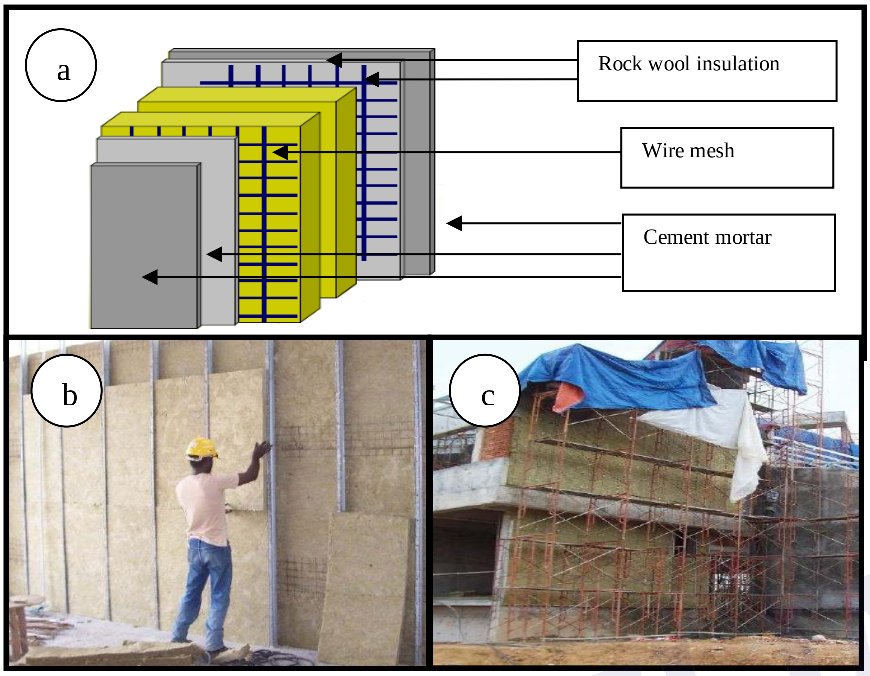

Figure 4.14: (a) Office building external wall (b) & (c) External wall installed with insulation system during construction of the building

(c) Roof

The roof section of the building is installed with Styrofoam with the aim to reduce the heat transfer through the roof and from entering the building. Below are the explanations of roof design of the building.

(i) Flat roof

The flat roofs of the office building are installed with 150mm thick Styrofoam as shown in Figure 4.15.

Figure 4.15: The photo shows the installation of Styrofoam during the construction of the roof

(ii) Slanting roof

Mineral wool is installed on the slanting roof as shown in Figure 4.16.

Figure 4.16: Mineral wool layer is installed on the slanting roof

(iii) Uppermost floor

The polystyrene layer is installed on the uppermost floor of the office building as shown in Figure 4.17, where the roof of the area houses the building integrated photovoltaic systems (BIPV).

Figure 4.17: Polystyrene layer is installed on the uppermost floor of the office building

4.3.4 Reduced internal load

Reducing the plug load is the approach taken by the Malaysia Green Technology Corporation in order to reduce the internal load. PC with CRT monitor is replaced by laptop or PC with LCD monitor.

4.3.5 Cooling system

The cooling system of the building encompasses rainwater collection, trickling cool roof, cooling tower, chiller, Air Handling Unit (AHU), Phase Change Material (PCM), and radiant cooling system.

4.3.5.1 Trickling cool roof

The trickling roof is an alternative approach to replace the cooling tower. At the night time or during the low operation period, the temperature of the water of the rainwater collection tank is reduced by draining through the trickling cool roof; the process is assisted by radiation, convection, evaporation, and also the low temperature from the surroundings which is 10 degree Celsius to 20 degree Celsius.

Next, the chilled water is drained to the chiller condenser; the chiller condenser functions as the heat eliminator. The chilled water is stored in the chiller and will be used for the next day. The process occurring on the trickling cool roof is shown in Figure 4.18.

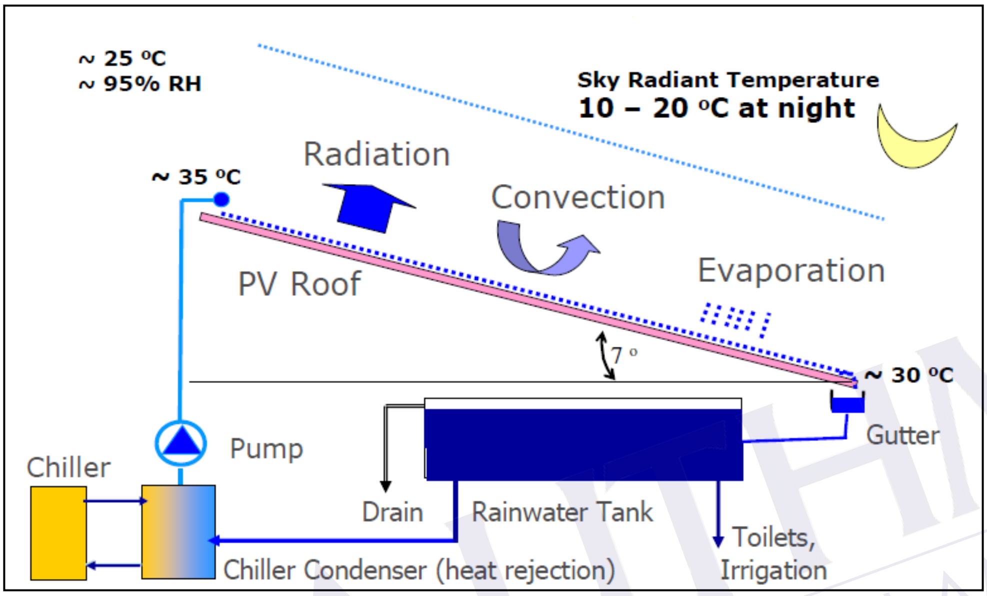

Figure 4.18: Cooling process happens on tricking cool roof

4.3.5.2 Cooling tower

Cooling tower in the Malaysia Green Technology Corporation office building has high energy-efficient characteristics. The usage of the cooling tower is complementing the trickling cool roof. Cooling tower will function when the trickling cool roof is not functioning.

4.3.5.3 Rainwater collection

The filtered rainwater will be used for cooling purposes, and also for the irrigation system of the building. The rainwater collection tank as shown in Figure 4.19 has a normal capacity which is 5280 gallons of water and its efficient capacity is 3700 gallons of water.

Figure 4.19: Rainwater collection tank

4.3.5.4 Phase Change Material (PCM)

Phase Change Material (PCM) functions in storage and release of thermal energy. PCM tank used in the building has a dimension of 3m x 3m x 2.5m as shown in Figure 4.20.

Figure 4.20: PCM plate flactice-10

4.3.5.5 Air Handling Unit (AHU)

Air Handling Unit (AHU) as shown in Figure 4.21 has high energy-efficient characteristics, in which its energy consumption is low compared to conventional AHU. Besides that the AHU has an energy consumption rate lower than 4kW. The AHU is installed with CO_2 detector and heat recovery wheel.

Figure 4.21: Air Handling Unit (AHU)

4.3.5.6 Variable Air Volume (VAV)/Variable Speed Drive (VSD)

In order to increase the energy efficiency of the cooling system, Malaysia Green Technology Corporation office building is equipped with Variable Air Volume (VAV), and Variable Speed Drive (VSD) as shown in Figure 4.22.

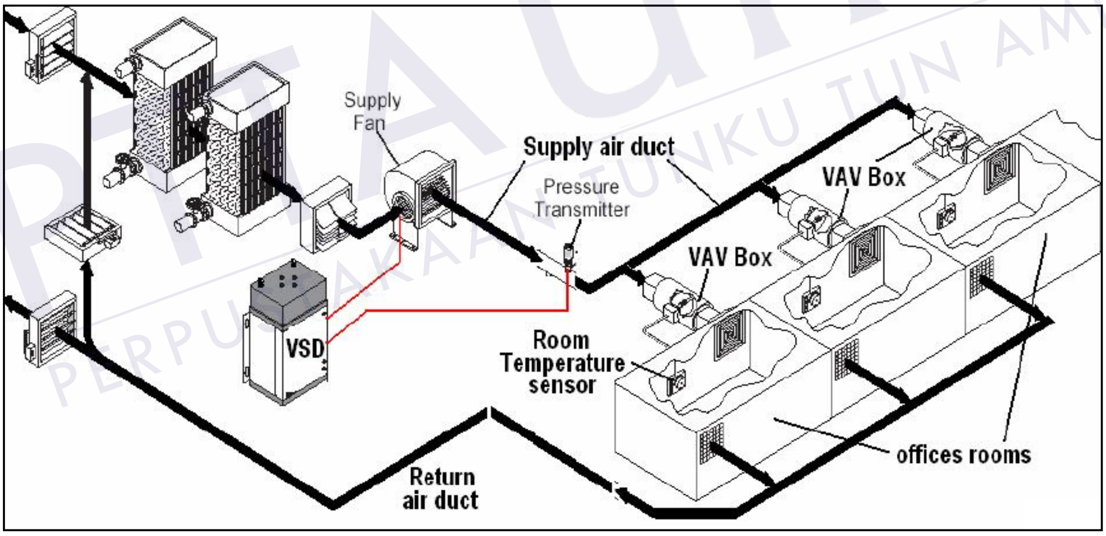

Figure 4.22: VAV and VSD system

4.3.5.7 Radiant cooling system

There are two types of radiant cooling system installed in the case study energy-efficient building. The systems are chilled slab and chilled metal ceiling.

(a) Chilled slab

The chilled slab is the slab installed with the PEX pipe, which functions to drain the coolant under the floor so that the temperature in the room can be reduced through reduction of floor temperature. Figure 4.23 shows PEX pipe installed in the slab during the construction.

Figure 4.23: PEX pipe installed on the slab during the construction process

(b) Chilled metal ceiling (CMC)

Chilled metal ceiling (CMC) has 18 degree Celsius of temperature; it is capable of reducing the room temperature from top to bottom. The installed panel has the cooling capacity of 93 watts/m^2 as shown in Figure 4.24.

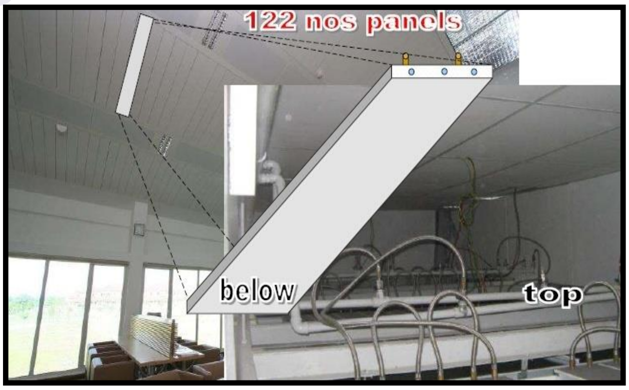

Figure 4.24: Chilled metal ceiling (CMC)

4.3.6 Energy-efficient lighting system

4.3.6.1 Energy-efficient electrical lighting system

Energy-efficient light, for example, T5 and CFL are installed with a proper circuit system. The goal is to reduce energy consumption. The LED task light used in the building has 6.2 watt energy consumption rate. The energy-efficient lights of the building have 300-400 Lux. as shown in Figure 4.25.

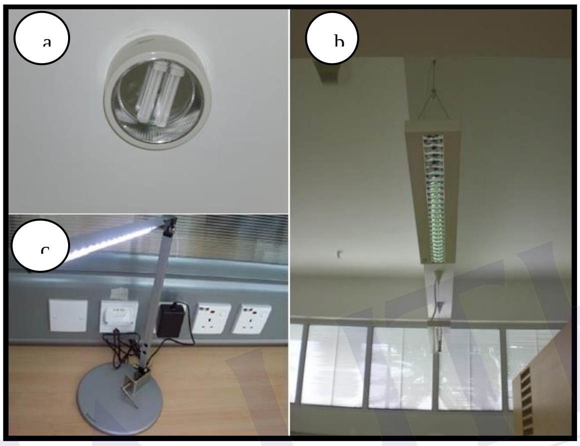

Figure 4.25: (a) Compact Fluorescent Light (CFL) (b) Fluorescent Light (c) LED Light

4.3.6.2 Control and sensors

Control and sensor system used in Malaysia Green Technology Corporation office building are daylight sensor and presence sensor as shown in Figure 4.26 and Figure 4.27.

Figure 4.26: Daylight sensor

Figure 4.27: Presence sensor

4.4 Energy-efficient and passive design components in the case study buildings

Table 4.2: Checklist of energy-efficient and passive design components in the case study buildings

No.	Energy-efficient and passive design components	Ministry of Energy, Green Technology and Water	Malaysia Green Technology Corporation	Energy Commission
1.	Building orientation	√	√	√
2.	Insulation system (external wall/internal wall/roof)	√	√	√
3.	Daylighting	√	√	√
4.	Skylight	√	√	√
5.	Daylight source from atrium roof	√	√	√
6.	Daylight source from the side of the building	√	√	√
7.	Internal layout	√	√	√
8.	Double glazing window	√	√	√
9.	Shading	√	√	√
10.	Reduced internal load	√	√	√
11.	Cooling system	√	√	√
12.	Trickling cool roof		√	
13.	Cooling tower	√	√	√
14.	Rainwater collection	√	√	√
15.	Phase change material (PCM)		√	√
16.	Variable air volume (VAV)	√	√	√
17.	Variable speed drive (VSD)	√	√	√
18.	Chilled slab		√	√
19.	Chilled metal ceiling		√	√
20.	Energy-efficient lighting system		√	√

The energy-efficient and passive designs components of the case study buildings can be summarized in Table 4.2. In summary, the identified energy-efficient and passive design components are building orientation, insulation system (external wall/internal wall/roof), daylighting, skylight, daylight source from atrium roof, daylight source from the side of the building, internal layout, double glazing window, shading, reduced internal load, cooling system, trickling cool roof, cooling tower, rainwater collection, passive change material (PCM), variable air volume (VAV), variable speed drive (VSD), chilled slab, chilled metal ceiling and energy-efficient lighting system.

The identified components were used as the information source for the mapping of previous studies process. The problems affecting the occupants' comfort were gathered from previous studies based on the identified energy-efficient and passive designs components in the case study buildings. This process is important to eliminate the unrelated energy-efficient and passive designs components which are not applied in the energy-efficient buildings built in hot and humid climatic region.

4.5 Mapping of previous studies (MPS)

The data collected from previous researches have successfully identified 49 of the energy-efficient design problems affecting occupants' comfort. The identified problems were then mapped into frequency table as shown in Table 4.3. Based on Table 4.3, the frequently occurred energy-efficient design problems affecting occupants' comfort are air conditioning system, natural ventilation system, window, radiant ceiling cooling system, radiant floor cooling system, artificial lighting, window shades, office layout, envelope tightness, and mechanical ventilation system. The IEQ criteria can be categorized into thermal comfort, Indoor Air Quality (IAQ), lighting, and acoustics. Each of the identified IEQ criteria and energy-efficient design components were later transformed into questionnaire format based on its nature of criteria.

Table 4.3: Energy-efficient design problems affecting occupants' comfort

		Steemers & Manchanda (2010)	*Wong et al. (2005)*	*Mumma (2002)*	*Lim et al. (2006)*	*Zhen & James (2006)*	*Raja et al. (2001)*	*Hua et al. (2011)*	*Galasiu & Veitch (2006)*	*Altan et al. (2008)*	*Bülow-Hübe (2008)*	*Wilkinson et. al. (2011)*	*Lee (2010)*	*Muehleisen (2010)*	*Taeyon & Jeong (2011)*	*Goins et al. (2010)*	*O'Brien et al. (2012)*	*Foster & Oreszczyn (2001)*	*Persson et al. (2006)*	*Wendt, et al., (2004)*	*Paul et al. (2010)*	*Crump et al. (2009)*	*Yu & Kim (2012)*	*Jensen et al. (2005)*	*Pank et al. (2008)*	*Yu et al. (2009)*	*Thomsen et al. (2005)*	***Frequency***	***IEQ Criteria***
Air conditioning system																													
1.	Lack of occupants control over air conditioning system.	√																										***1***	Thermal comfort
2.	Low indoor air quality pose a threat to human health																									√		***1***	Indoor Air Quality (IAQ)
3.	Noise caused by heat pump compressor																										√	***1***	Acoustics
Natural ventilation system																													
4.	Lack of occupants control over ventilation system (window) caused thermal discomfort.	√					√																					***2***	Thermal comfort
5.	Lack of cross ventilation																										√	***1***	Thermal comfort
6.	Excessive noise													√														***1***	Acoustics

Thermal comfort Indoor Air Quality (IAQ) Lighting Acoustics

Table 4.3: Continued

		Steemers & Manchanda (2010)	*Wong et al. (2005)*	*Mumma (2002)*	*Lim et al. (2006)*	*Zhen & James (2006)*	*Raja et al. (2001)*	*Hua et al. (2011)*	*Galasiu & Veitch (2006)*	*Altan et al. (2008)*	*Bülow-Hübe (2008)*	*Wilkinson et. al. (2011)*	*Lee (2010)*	*Muehleisen (2010)*	*Taeyon & Jeong (2011)*	*Goins et al. (2010)*	*O'Brien et al. (2012)*	*Foster & Oreszczyn (2001)*	*Persson et al. (2006)*	*Wendt, et al., (2004)*	*Paul et al. (2010)*	*Crump et al. (2009)*	*Yu & Kim (2012)*	*Jensen et al. (2005)*	*Pank et al. (2008)*	*Yu et al. (2009)*	*Thomsen et al. (2005)*	***Frequency***	***IEQ Criteria***
Window																													
7.	(Large window area) Fully glazed façade cause thermal discomfort due to high solar gain.		√							√	√							√	√									***5***	
8.	High intensity solar radiation transmitting through the glazed areas can cause unwanted glare effect									√					√			√										***3***	
9.	Lack of speech clarity													√														***1***	
10.	Lack of speech privacy													√														***1***	
Radiant ceiling cooling system																													
11.	Condensation			√																								***1***	
12.	Radiant asymmetry			√																								***1***	

Thermal comfort — Indoor Air Quality (IAQ) — Lighting — Acoustics

Table 4.3: Continued

		Steemers & Manchanda (2010)	*Wong et al. (2005)*	*Mumma (2002)*	*Lim et al. (2006)*	*Zhen & James (2006)*	*Raja et al. (2001)*	*Hua et al. (2011)*	*Galasiu & Veitch (2006)*	*Altan et al. (2008)*	*Bülow-Hübe (2008)*	*Wilkinson et. al. (2011)*	*Lee (2010)*	*Muehleisen (2010)*	*Taeyon & Jeong (2011)*	*Goins et al. (2010)*	*O'Brien et al. (2012)*	*Foster & Oreszczyn (2001)*	*Persson et al. (2006)*	*Wendt, et al., (2004)*	*Paul et al. (2010)*	*Crump et al. (2009)*	*Yu & Kim (2012)*	*Jensen et al. (2005)*	*Pank et al. (2008)*	*Yu et al. (2009)*	*Thomsen et al. (2005)*	***Frequency***	***IEQ Criteria***
Radiant floor cooling system																													
13.	Floor surface condensation				√																							***1***	
14.	Radiant asymmetry caused local discomfort				√	√																						***2***	
Artificial lighting																													
15.	Lack of occupants control over artificial lighting							√																				***1***	
16.	Limitations of current knowledge about how people respond to artificial lighting								√																			***1***	

Thermal comfort   Indoor Air Quality (IAQ)   Lighting   Acoustics

Table 4.3: Continued

		Steemers & Manchanda (2010)	*Wong et al. (2005)*	*Mumma (2002)*	*Lim et al. (2006)*	*Zhen & James (2006)*	*Raja et al. (2001)*	*Hua et al. (2011)*	*Galasiu & Veitch (2006)*	*Altan et al. (2008)*	*Bülow-Hübe (2008)*	*Wilkinson et. al. (2011)*	*Lee (2010)*	*Muehleisen (2010)*	*Taeyon & Jeong (2011)*	*Goins et al. (2010)*	*O'Brien et al. (2012)*	*Foster & Oreszczyn (2001)*	*Persson et al. (2006)*	*Wendt, et al., (2004)*	*Paul et al. (2010)*	*Crump et al. (2009)*	*Yu & Kim (2012)*	*Jensen et al. (2005)*	*Pank et al. (2008)*	*Yu et al. (2009)*	*Thomsen et al. (2005)*	***Frequency***	***IEQ Criteria***
Window shades																													
17.	Lack of occupants control over window shades of the building							√									√											***2***	
18.	Limitations of current knowledge about how people respond to window shades control								√																			***1***	
19.	Unqualified shade materials														√													***1***	
20.	Logic error of shade														√													***1***	
21.	Lack of solar shading																										√	***1***	
Office layout																													
22.	Lack of privacy (speech)											√				√								√				***3***	
23.	Poor visual privacy												√															***1***	
24.	Noise problems											√	√											√				***3***	

Thermal comfort Indoor Air Quality (IAQ) Lighting Acoustics

Table 4.3: Continued

		Steemers & Manchanda (2010)	*Wong et al. (2005)*	*Mumma (2002)*	*Lim et al. (2006)*	*Zhen & James (2006)*	*Raja et al. (2001)*	*Hua et al. (2011)*	*Galasiu & Veitch (2006)*	*Altan et al. (2008)*	*Bülow-Hübe (2008)*	*Wilkinson et. al. (2011)*	*Lee (2010)*	*Muehleisen (2010)*	*Taeyon & Jeong (2011)*	*Goins et al. (2010)*	*O'Brien et al. (2012)*	*Foster & Oreszczyn (2001)*	*Persson et al. (2006)*	*Wendt, et al., (2004)*	*Paul et al. (2010)*	*Crump et al. (2009)*	*Yu & Kim (2012)*	*Jensen et al. (2005)*	*Pank et al. (2008)*	*Yu et al. (2009)*	*Thomsen et al. (2005)*	***Frequency***	***IEQ Criteria***
Envelope tightness																													
25.	Tight envelope aggravates potential Indoor Air Quality (IAQ).																			√								***1***	
26.	Air-tightness of the façade causes problems with controlling internal temperatures																								√			***1***	
27.	Draft																								√			***1***	
Mechanical ventilation system																													
28.	Increased dust particle																				√							***1***	
29.	Moisture in building																				√							***1***	
30.	Produce noise																					√					√	***2***	
31.	Produce cold draught while in operation																					√						***1***	
32.	Ineffectiveness of the ventilation system for removal of VOCs																						√					***1***	
33.	Draught problems																										√	***1***	

Thermal comfort | Indoor Air Quality (IAQ) | Lighting | Acoustics

4.6 Questionnaire development

The information gathered from mapping of previous studies was used for the formation of initial questionnaire template, IEQ variables, and energy-efficient design variables were identified. The obtained information was used to formulate the Energy-Efficient Building Environmental Quality Evaluation Framework as shown in Figure 4.28.

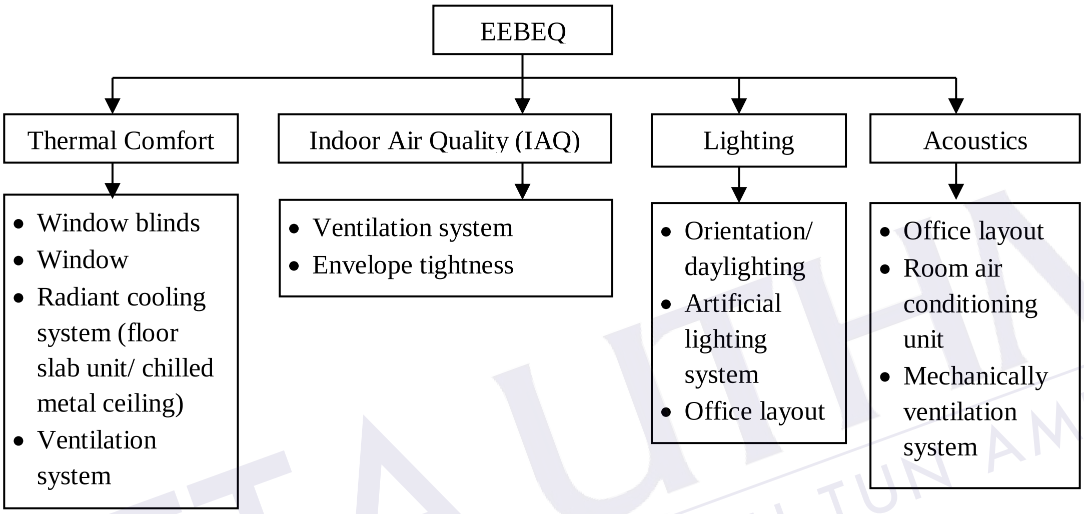

Figure 4.28: EEBEQ, energy-efficient design variables and Indoor Environmental Quality (IEQ) variables

The questions arrangement starts from the highest occurrence frequency of the IEQ criteria to the lowest occurrence frequency. The occurrence frequency of the IEQ criteria is shown in Figure 4.29. The occurrence frequency was determined through the mapping of previous studies. In the EEBEQ the question in section B is begun with thermal comfort, and followed by acoustics, lighting, and Indoor Air Quality (IAQ). The IEQ can be considered both as technical concept and human experience. In the EEBEQ, there is a focus on human experience; questions regarding everyday use experience of energy-efficient design variables were formed. The Energy-Efficient Building Environmental Quality Evaluation Framework is shown in **Appendix A-I**.

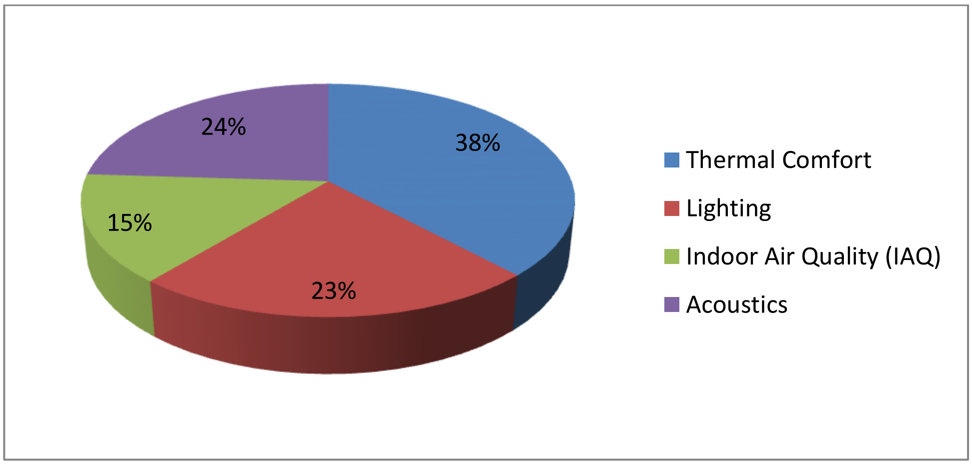

Figure 4.29: Frequency of IEQ criteria

Section A

This section contains questions regarding to respondents' background information; gender, age, highest education level, occupational level, years of using this building, and location of occupant in this building.

The variables and its explanation are as follows:

1. Gender

   Sex: male or female
2. Age

   How old are the respondents
3. Highest Education Level

   The highest education achieved by the respondents
4. Occupational Level

   The present position in the organization
5. Years of using this building

   Number of years working in this building
6. The floor level of the workplace

   The floor level of respondents' workplace
7. Number of people working in your workplace

   The amount of people working in a room
8. Description of the respondent's workplace

   Situated near or far away from the window

Section B

This section comprises of four criterions and ten parameters. According to the description of each criterion parameter, respondents were asked to rank their satisfaction level on each criterion parameter. In this section the Likert scale is used to rank the satisfaction level from Low range to High range (1-7). The indication of each range is shown in Table 4.4. The advantage of a 7-point scale over a 4- or 5-point scale is the ability to detect smaller differences (Veldhuyzen van zanten *et al.*, 2006).

Table 4.4: Level of agreement scale

Scale	Satisfaction Level
1	Strongly Disagree
2	Disagree
3	Disagree somewhat
4	Undecided
5	Agree somewhat
6	Agree
7	Strongly agree

The criterions parameters are as follows:

1. Thermal comfort
   - (i) Window blinds/shades
   - (ii) Window
   - (iii) Room air-conditioning unit/Floor slab cooling/Chilled metal ceiling
   - (iv) Ventilation system
2. Acoustic
   - (i) Office Layout
   - (ii) Room air conditioning unit
   - (iii) Mechanically ventilation system
3. Lighting
   - (i) Orientation/Daylighting (*window/skylight*)
   - (ii) Artificial lighting system
   - (iii) Office Layout
4. Air quality
   - (i) Envelope tightness
   - (ii) Ventilation system

4.7 Content validity test analysis

A content evaluation panel expert will normally comprise of the identified domains, or a domain universe in which the judgments are to be made (Allahyari *et al.*, 2011). Hence in this research, content evaluation panel experts were chosen among the key peoples in the energy-efficient building development fields such as energy consultant, and architects who are involved in the energy-efficient buildings development projects, and also the experienced academician from built environmental fields. Table 4.5 shows the composition of the panel of experts. There is a total of 5 panel of experts that have been selected; according to Lawshe Method of content validation only a minimum of 5 panelists are required for the content validation process. The judgments of the panelists were calculated using statistical and mathematical calculations via Microsoft Excel. The methods involved are the Content Validity Ratio (CVR) and means of judgment of the panelists as suggested by Allahyari *et al.* (2011).

Table 4.5: Composition of panel of experts

Expert Type	Number
Architects	3
Academicians	1
Energy Consultants	1
Total	5

(a) Quantifying of consensus among panelists

The Content Validity Ratio (CVR):

$$CVR = (n_e - n/2)/(n/2)$$

n_e = number of panelists indicating “essential”

n/2 = number of panelists divided by two

CVR = direct linear transformation from the panelists saying “essential”

(b) Calculation of the respective judgments means

The following conversion was done for the values reflected in the questionnaire in order to compute the mean for each item:
Low relevant – was replaced by 0
Moderate relevant – was replaced by 1
High relevant – was replaced by 2

(c) The selection of the accepted questions

(i) Accept unconditionally if CVR is equal to or larger than 0.99 referring to Table 3.2 in Chapter 3.

(ii) Accept if CVR is between 0 and 0.99 and the mean of judgments higher than 1.5. A value of higher than 1.5 indicates the mean of judgments is closer to the value of High Relevant.

(iii) Reject, if CVR is less than 0 and the mean is lower than 1.5.

Table 4.6: Means and CVR values of the respective judgments and acceptation or rejection result

Number of items	CVR	Mean	Accept/Reject
1- Gender	1	1.6	Accepted
2- Age	1	1.6	Accepted
3 - Education level	1	1.6	Accepted
4 - Occupational level	1	1.6	Accepted
5 - How many years have you been working in this building	1	1.6	Accepted
6- Which floor is your workplace	1	1.6	Accepted
7 - How many colleagues are working in the same area with you	1	1.6	Accepted
8 - Description of your workplace	1	1.8	Accepted
9 - I can still feel the heat of the sun coming through the window although the window blinds in my working area has been pulled down	1	1.8	Accepted
10 - I can still feel the heat of the sun coming through the window while sitting or standing near to the windows that have window shades	0.6	1.6	Accepted
11 - The current window blinds control system doesn't work according to your desire	1	1.6	Accepted
12 - Do you agree that a good window blinds control system contributes better thermal comfort	1	2	Accepted
13 - The window blinds control system is often down	1	1.8	Accepted
14 - I have to pull down window blinds in order to reduce the heat coming from outside of the building	1	1.6	Accepted
15 - There are too many windows in your workplace and causing you to feel uncomfortable due to the heat of the sun	1	2	Accepted
16 - The current window control system doesn't work according to your desire	1	1.6	Accepted
17 - Do you agree a good window control system contribute better thermal comfort	1	1.6	Accepted
18 - The window control systems is often down	1	2	Accepted
19 - The air conditioning system doesn't provide comfortable room temperature	1	2	Accepted
20 - The air conditioning system in the office is often down	1	2	Accepted
21 - Do you agree the current air conditioning control system doesn't work according your desire	1	1.8	Accepted
22 - Do you agree a good air conditioning control system contributes better thermal comfort	1	1.8	Accepted
23 - The air conditioning control systems is often down	0.6	1.6	Accepted
24 - The floor surface in the office is always slippery (not caused by cleaning chore)	1	1.8	Accepted
25 - Part of the ceiling in the office looks moist and causes water drop	0.6	1.6	Accepted
26 - Most of the staff including you feel radiant asymmetry (local cold discomfort in the arm-hand and the leg-foot regions)	1	2	Accepted
27 - The ventilation system in the office building is performing well	1	2	Accepted
28 - Do you that agree a good ventilation system contributes better thermal comfort	1	1.8	Accepted
29 - The ventilation system in the office building is often down	1	1.8	Accepted
30 - Do you agree that the current ventilation control system doesn't work according to your desire	1	2	Accepted
31 - Do you agree that a good ventilation control system contributes better thermal comfort	1	2	Accepted
32 - The ventilation control system is often down	1	1.8	Accepted
33 - Your current workplace is stuffy	1	2	Accepted
34 - Is your working area affected by odor	1	2	Accepted

Table 4.6: Continued

Number of items	CVR	Mean	Accept/Reject
35 - The doors which connect to outside room/office building are often remained unclosed/not fully closed	0.6	1.6	Accepted
36 - The windows connecting to the outside room/office building is often remained unclosed/not fully closed	0.6	1.6	Accepted
37 - The natural daylight in the office building is sufficient for you to execute your work	1	2	Accepted
38 - The position of the window in the office building is suitable in providing maximum daylight	1	2	Accepted
39 - Do you agree that additional artificial light (eg. desk lamp) is needed while you are working	1	1.8	Accepted
40 - Are you often interrupted by the glare/reflection caused by natural daylight while working	1	2	Accepted
41 - Are the artificial lights in the office building not efficient	1	2	Accepted
42 - The artificial lights in the office building are not often functioning	1	2	Accepted
43 - As an occupant in the office building, do you agree that artificial lightings are often used by you and your colleague	1	2	Accepted
44 - Do you agree that the current control system doesn't work according to your will	1	2	Accepted
45 - Do you agree that a good control system contributes better lighting	1	1.8	Accepted
46 - The artificial lighting control system is often down.	1	2	Accepted
47 - The arrangement of cubicle/working table (allowing light to permit into your workplace)	1	1.8	Accepted
48 - The types of working table you are using do not obstruct daylight but permit sufficient daylight while you are working	1	1.8	Accepted
49 - Too much of open space in the working area can cause distractions while working when others are making their conversation	1	2	Accepted
50 - Too much of glass material (partition/window)causes echo effect	1	2	Accepted
51 - The air conditioning unit is causing unwanted noise while in use	1	1.8	Accepted
52 - The mechanical ventilation system is causing unwanted noise while in use	1	2	Accepted

Based on Table 4.6, the results from the content validation show that the overall contents of the questionnaire form were accepted. For question 10, 23, 25, 35, and 36, although the CVR value is below 0.99, the questions are considered as accepted due to the fact that their mean values are above 1.5, which means that the mean of judgments is closer to the value of High Relevance. The CVR value 1 indicated high consensus among panelists and those questions were accepted unconditionally. The Content Validity Index (CVI) was estimated after the calculation of the CVR values. The CVI is the mean of the CVR values of items retained in the validated procedure. CVI presents the commonality of judgments regarding the validity. The overall content validity will be higher if the value of the CVI is closer to 0.99 and vice versa (Lawshe, 1975).

CVI results,

$$CVI = \frac{\sum_{n}^{1} CVR}{Retained\ numbers}$$

$$CVI = \frac{50}{52} = 0.96$$

The CVI value for the Energy-Efficient Building Environmental Quality Evaluation Framework is 0.96; hence it shows high content validity of the questionnaire.

4.8 Data analysis

The newly designed EEBEQ was tested at the Malaysia Green Technology Corporation, Energy Commission, and Ministry of Energy, Green Technology and Water office building as shown in Figure 4.30. The data gathered from the respondents were analyzed and the reliability and validity of the EEBEQ were determined through data analysis. The data analysis was conducted using software package SPSS Version 17.0.

4.8.1 Sampling analysis

Questionnaires have been distributed to the occupants from the case study buildings, 30 percents of the population from each building have been asked to fill out the questionnaire form. Only the fully answered questionnaires forms were selected as the sample of this study. During the research, 65, 24, and 45 sets of questionnaires have been distributed to the occupants from Building A - Ministry of Energy, Green Technology and Water, Building B - Malaysia Green Technology Corporation, and Building C - Energy Commission respectively. The return rates of questionnaires for each case study buildings are shown in Table .4.7.

(a) The interior of the Ministry of Energy, Green Technology and Water building

(b) The interior of the Malaysia Green Technology Corporation building

(c) The interior of the Energy Commission building

Figure 4.30: The interior of the case studies building

Table 4.7: Sample size and questionnaire form return rate

	Building A	**Building B**	**Building C**
Population	200	80	150
No. of distributed questionnaire	65	24	45
Returned questionnaires with fully answered	54	20	37
Response rate (%)	83.08	83.33	82.22

Based on Table 4.7, out of 134 sets of questionnaire distributed to the selected respondents from case study buildings, 111 sets (82.84%) were returned. 65 sets were distributed to respondents from Building A and 54 (83.08%) were returned, while 24 sets were distributed to respondents from Building B with a return rate of 20 (83.33%), and 45 sets of questionnaire were distributed to respondents from Building C and 37 (82.22%) were returned.

Table 4.8, Table 4.9, and Table 4.10 show the background of the respondents from case study buildings; Building A, Building B, and Building C. The tables provide information regarding the composition of the sample size based on the variability in terms of location of their workplace and the description of the workplace. In order to produce a realistic outcome, it is important that the samples are chosen from among the respondents of different background (Munusamy *et al.*, 2010). This is because the different workplace locations will most certainly generate more reliable outcomes.

Table 4.8: Building A – Respondents' background

	%		%
Gender		***Floor (workplace)***	
Male	42.6	2	87.0
Female	57.4	3	13.0
Age		***No. of colleagues***	
20 – 29	42.6	2	13.0
30 – 39	37.0	4	5.6
40 – 49	20.4	5	24.1
		6	20.4
		7	13.0
		8	5.6
		10	18.5
Education Level		***No. of years working in this building***	
Secondary (form 1 – 5)	3.7	1	7.4
University/College		2	11.1
(Diploma-1st Degree)	96.3	3	7.4
		4	18.5
		5	22.2
		6	25.9
		8	7.4
Occupational Level		***Description of workplace***	
Administrative	3.7	Facing the window	27.8
Management	55.6	Backing the window	29.6
Executive	25.9	Side to the window	29.6
Secretarial	9.3	No window	13.0
Technical	3.0		

Table 4.9: Building B – Respondents' background

	%		%
Gender		***Floor (workplace)***	
Male	60.0	2	55.0
Female	40.0	3	45.0
Age		***No. of colleagues***	
20 – 29	25.0	3	25.0
30 – 39	50.0	4	15.0
40 – 49	25.0	5	15.0
		7	25.0
		8	20.0
Education Level		***No. of years working in this building***	
Secondary (form 1 – 5)	10.0	1	15.0
Pre-U (Form 6/equivalent)	20.0	2	15.0
University/College		3	20.0
(Diploma-1st Degree)	70.0	4	20.0
		5	15.0
		6	10.0
		7	5.0
Occupational Level		***Description of workplace***	
Administrative	15.0	Facing the window	10.0
Management	35.0	Backing the window	30.0
Executive	10.0	Side to the window	60.0
Secretarial	20.0		
Technical	20.0		

Table 4.10: Building C – Respondents' background

	%		%
Gender		***Floor (workplace)***	
Male	54.1	4	29.7
Female	45.9	5	40.5
		6	29.7
Age		***No. of colleagues***	
20 – 29	10.8	4	10.8
30 – 39	48.6	5	8.1
40 – 49	40.5	10	18.9
		12	18.9
		14	24.3
		16	18.9
Education Level		***No. of years working in this building***	
Secondary (form 1 – 5)	5.4	1	37.8
Pre-U (Form 6/equivalent)	8.1	2	32.4
University/College		3	29.7
(Diploma-1st Degree)	86.5		
Occupational Level		***Description of workplace***	
Administrative	21.6	Facing the window	29.7
Management	43.2	Backing the window	35.1
Executive	18.9	Side to the window	29.7
Secretarial	10.8	No window	5.4
Technical	5.4		

Based on Table 4.8, Table 4.9, and Table 4.10, the questionnaires were distributed to the respondents of the case study buildings from different background. The important questions such as description of workplace, years of working in this building, and floor of the workplace play crucial parts in providing reliable results.

Although, energy-efficient buildings are designed with sufficient window features in order to provide sufficient daylight to building's occupants while working, yet there are extremely high numbers of respondents from Building A (13.0%) compared to Building B and Building C working in a workplace with no window features. This is because, Building A had undergone renovation in the past few years and the former corridor area have been converted into office space which is due to the increasing number of occupants and thus will certainly affect the IEQ score for Building A.

4.8.2 Reliability test analysis

Cronbach's Alpha was used to evaluate the internal consistency of the questionnaire. Cronbach's Alpha is able to help in identifying redundant items in the questionnaire. High Cronbach's Alpha shows no redundant items or repeated questions in the questionnaire. The Cronbach's Alpha for this research is shown as below.

Table 4.11: Cronbach's Alpha for Building A, Building B, and Building C

	Cronbach's Alpha	N of items
Building A	0.7326	52
Building B	0.7065	52
Building C	0.7440	52

Based on Table 4.11, Cronbach's Alpha for Building A, Building B, and Building C are 0.7326, 0.7065, and 0.7440 respectively. The numbers are greater than 0.7. Hence, it is concluded that the consistency of the retrieved data is high and there is no redundant item in the questionnaire and no item was deleted. Overall, the data collected from Building A, Building B, and Building C are acceptable.

4.8.3 Test-retest reliability

The respondents who have answered the questionnaire during the pilot test were asked to answer the same questionnaire form after two weeks of the initial pilot test carried out. This process is important to test the reliability of each question. It is hypothesized that, respondents will give the same answer after two weeks of initial pilot test. For test-retest reliability, intra-class correlation coefficients (ICCs) were computed to assess how much of the total variance of the subscale between respondents when the test was carried out two weeks after the initial pilot test. The result of the ICC reliability is shown in Table 4.12.

Table 4.12: ICC Reliability of (EEBEQ)

Number of items	ICC Value
1- Gender	1.00
2- Age	1.00
3 - Education level	1.00
4 - Occupational level	1.00
5 - How many years have you been working in this building	1.00
6- Which floor is your workplace	1.00
7 - How many colleagues are working in the same area with you	1.00
8 - Description of your workplace	1.00
9 - I can still feel the heat of the sun coming through the window although the window blinds in my working area has been pulled down	0.51
10 - I can still feel the heat of the sun coming through the window while sitting or standing near to the windows that have window shades	0.91
11 - The current window blinds control system doesn’t work according to your desire	0.62
12 - Do your agree that a good window blind control system contributes better thermal comfort	0.60
13 - The window blinds control system is often down	0.91
14 - I have to pull down window blinds in order to reduce the heat coming from outside of the building	0.67
15 - There are too many windows in your workplace and causing you to feel uncomfortable due to the heat of the sun	0.71
16 - The current window control system doesn't work according to your desire	0.71
17 - Do you agree that a good window control system contributes better thermal comfort	0.49
18 - The window control systems is often down	0.75
19 - The air conditioning system doesn't provide comfortable room temperature	0.90
20 - The air conditioning system in the office is often down	0.60
21 - Do you agree that the current air conditioning control system doesn't work according your desire	0.51
22 - Do you agree that a good air conditioning control system contributes better thermal comfort	0.75
23 - The air conditioning control systems is often down	0.74
24 - The floor surface in the office is always slippery (not caused by cleaning chore)	0.84
25 - Part of the ceiling in the office looks moist and causes water drop	0.81
26 - Most of the staff including you feel radiant asymmetry (local cold discomfort in the arm-hand and the leg-foot regions)	0.63
27 - The ventilation system in the office building is performing well	0.87
28 - Do you agree that a good ventilation system contributes better thermal comfort	0.66
29 - The ventilation system in the office building is often down	0.86
30 - Do you agree that the current ventilation control system doesn't work according to your desire	0.88
31 - Do you agree that a good ventilation control system contributes better thermal comfort	0.68
32 - The ventilation control system is often down	0.62
33 - Your current workplace is stuffy	0.87
34 - Is your working area affected by odor	0.88
35 - The doors which connect to outside room/office building are often remained unclosed/not fully closed	0.71
36 - The windows connect to the outside room/office building is often remained unclosed/not fully closed	0.57
37 - The natural daylight in the office building is sufficient for you to execute your work	0.52

Table 4.12: Continued

Number of items	ICC Reliability
38 - The position of the window in the office building is suitable in providing maximum daylight	0.86
39 - Do you agree that additional artificial light (eg. desk lamp) is needed while you are working	0.89
40 - Are you often interrupted by the glare/reflection caused by natural daylight while working	0.91
41 - Are the artificial lights in the office building not efficient	0.83
42 - The artificial lights in the office building are not often functioning	0.70
43 - As an occupant in the office building, do you agree that artificial lightings are often used by you and your colleague	0.96
44 - Do you agree that the current control system doesn't work according to your will	0.51
45 - Do you agree that a good control system contributes better lighting	0.70
46 - The artificial lighting control system is often down.	0.48
47 - The arrangement of cubicle/working table (allowing light to permit into your workplace)	0.84
48 - The types of working table you are using do not obstruct daylight but permit sufficient daylight while you are working	0.83
49 - Too much of open space in the working area can cause distractions while working when others are making their conversation	0.79
50 - Too much of glass material (partition/window)causes echo effect	0.86
51 - The air conditioning unit causes unwanted noise while in use	0.87
52 - The mechanical ventilation system causes unwanted noise while in use	0.62

Based on Table 4.12, all questions from the EEBEQ show high test-retest reliability with the ICC value ranging from 0.51 to 1.00. Since the respondents were selected from the same group of peoples, hence questions 1 to 9 which are related to respondents' background score an exceptionally high reliability with the ICC value of 1.00. Meanwhile, other questions showed an acceptable ICC value 0.51 to 0.91. It is concluded that the hypothesis is accepted and the respondents make the same judgment though the questionnaire were distributed in the different time frame. This also shows high consistency of the EEBEQ.

4.8.4 Criterion validity analysis

The result of thermal comfort, acoustics, lighting, and Indoor Air Quality (IAQ) from EEBEQ were compared with the BUS. The difference between EEBEQ and BUS is that the EEBEQ questions are computed based on the information of energy-efficient design whereas questions from BUS revolve around some general perceptions towards the IEQ criteria. Since the EEBEQ and BUS are both studying the IEQ performance of the building, thus it is hypothesized that both questionnaires will achieve the same result outcome. The process of comparing the criteria result from newly designed EEBEQ and the BUS questionnaire is important in order to determine whether the newly designed evaluation framework fulfills the purpose of the design intention in the first place. The results of the criterion validity analysis are shown in Table 4.13, Table 4.14, Table 4.15, and Table 4.16 for Building A, Table 4.19, Table 4.20, 4.21, and Table 4.22 for Building B, and Table 4.23, Table 4.24, Table 4.25, and Table 4.26 for Building C.

4.8.4.1 Building A

Table 4.13: Correlation of thermal comfort – Building A

		Thermal Comfort (BUS)	Thermal Comfort (EEBEQ)
Thermal Comfort (BUS)	Pearson Correlation	1	.366(**)
	Sig. (2-tailed)	.	.006
	N	54	54
Thermal Comfort (EEBEQ)	Pearson Correlation	.366(**)	1
	Sig. (2-tailed)	.006	.
	N	54	54

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.14: Correlation of acoustics – Building A

		Acoustics (BUS)	Acoustics (EEBEQ)
Acoustics (BUS)	Pearson Correlation	1	.399(**)
	Sig. (2-tailed)	.	.003
	N	54	54
Acoustics (EEBEQ)	Pearson Correlation	.399(**)	1
	Sig. (2-tailed)	.003	.
	N	54	54

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.15: Correlation of lighting – Building A

		Lighting (BUS)	Lighting (EEBEQ)
Lighting (BUS)	Pearson Correlation	1	.190
	Sig. (2-tailed)	.	.169
	N	54	54
Lighting (EEBEQ)	Pearson Correlation	.190	1
	Sig. (2-tailed)	.169	.
	N	54	54

Table 4.16: Correlation of Indoor Air Quality (IAQ) – Building A

		Indoor Air Quality (BUS)	Indoor Air Quality (EEBEQ)
IAQ (BUS)	Pearson Correlation	1	.589(**)
	Sig. (2-tailed)	.	.000
	N	54	54
IAQ (EEBEQ)	Pearson Correlation	.589(**)	1
	Sig. (2-tailed)	.000	.
	N	54	54

** Correlation is significant at the 0.01 level (2-tailed).

Based on Table 4.13, Table 4.14, Table 4.15, and Table 4.16 which the result of correlation between BUS and EEBEQ for Building A, it is shown that there is a presence of high correlation in terms of thermal comfort, acoustics, and Indoor Air Quality (IAQ). The thermal comfort (BUS) and thermal comfort (EEBEQ) score 0.366 in correlation, acoustics (BUS) and acoustics (EEBEQ) score 0.399 in correlation and Indoor Air Quality (BUS) and Indoor Air Quality (EEBEQ) has scored a perfect correlation which is 0.589. Although, thermal comfort, acoustics and Indoor Air Quality (IAQ) recorded a high correlation between BUS and EEBEQ, yet the lighting criteria for BUS and EEBEQ have shown no correlation. The reason of this can be caused by the renovation of Building A. Part of the building has been renovated due to the increase of workers in the building, and the previous corridor area has been renovated and turned into office space as shown in Figure 4. This might cause low satisfaction of the occupants who are working in the renovated area with less window features as shown in Figure 4.31.

Figure 4.31: Picture on the left shows the exterior of the renovated area and picture on the right shows the interior of the renovated area.

In order to further investigate the problems and to prove the assumption of the low satisfaction encountered by occupants who are working in the renovated area, a descriptive analysis was conducted in order to get a clearer picture about the occupants' perception as shown in Table 4.17 and Table 4.18.

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Table 4.17: Descriptive analysis of lighting (EEBEQ) – Building A

	N	Minimum	Maximum	Mean
The natural daylight in the office building is sufficient for you to execute your work	54	2.00	6.00	4.2407
The position of the window in the office building is suitable in providing maximum daylight	54	2.00	6.00	3.5000
Do you agree that additional artificial light (eg. desk lamp) is needed while you are working	54	2.00	7.00	4.9259
Are you often interrupted by the glare/reflection caused by natural daylight while working	54	2.00	6.00	3.1852
Are the artificial lights in the office building not efficient	54	1.00	5.00	2.4074
The artificial lights in the office building are not often functioning	54	1.00	5.00	2.5370
As the occupants in the office building do you agree that artificial lightings are often used by you and your colleague	54	1.00	7.00	3.5370
Do you agree that the current control system doesn't work according to your will	54	1.00	7.00	2.7593
Do you agree that a good control system contributes better lighting	54	2.00	7.00	5.3704
The artificial lighting control system is often down.	54	1.00	6.00	2.2778

Table 4.17: Continued

	N	Minimum	Maximum	Mean
The arrangement of cubicle/working table (allowing light to permit into your workplace)	54	3.00	7.00	5.3148
The types of working table you are using do not obstruct daylight but permit sufficient daylight while you are working	54	2.00	7.00	5.1481
Valid N (listwise)	54			

Table 4.18: Descriptive analysis of lighting (BUS) – Building A

	N	Minimum	Maximum	Mean
Natural light	54	2.00	6.00	4.2963
Glare from sun and sky	54	1.00	4.00	2.7963
Artificial light	54	2.00	6.00	4.1852
Glare from lights	54	1.00	6.00	3.1111
Valid N (listwise)	54			

Based on Table 4.17, the question about whether or not the position of the window in the office building is suitable in providing maximum daylight, the results show less satisfaction or low agreement; this is correlated with the real office condition where some of the workplace areas have limited window features. This shows that EEBEQ is able to detect the inefficiency of the building design compared to BUS. The questions from BUS only cover the general situation of the office building and are not capable to identify the problems causing inefficiency of the IEQ performance.

4.8.4.2 Building B

Table 4.19: Correlation of thermal comfort – Building B

		Thermal Comfort (BUS)	Thermal Comfort (EEBEQ)
Thermal Comfort (BUS)	Pearson Correlation	1	.702(**)
	Sig. (2-tailed)	.	.001
	N	20	20
Thermal Comfort (EEBEQ)	Pearson Correlation	.702(**)	1
	Sig. (2-tailed)	.001	.
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.20: Correlation of acoustics – Building B

		Acoustics (BUS)	Acoustics (EEBEQ)
Acoustics (BUS)	Pearson Correlation	1	.476(*)
	Sig. (2-tailed)	.	.034
	N	20	20
Acoustics (EEBEQ)	Pearson Correlation	.476(*)	1
	Sig. (2-tailed)	.034	.
	N	20	20

* Correlation is significant at the 0.05 level (2-tailed).

Table 4.21: Correlation of lighting – Building B

		Lighting (BUS)	Lighting (EEBEQ)
Lighting (BUS)	Pearson Correlation	1	.622(**)
	Sig. (2-tailed)	.	.003
	N	20	20
Lighting (EEBEQ)	Pearson Correlation	.622(**)	1
	Sig. (2-tailed)	.003	.
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.22: Correlation of Indoor Air Quality (IAQ) – Building B

		IAQ (BUS)	IAQ (EEBEQ)
IAQ (BUS)	Pearson Correlation	1	.619(**)
	Sig. (2-tailed)	.	.004
	N	20	20
IAQ (EEBEQ	Pearson Correlation	.619(**)	1
	Sig. (2-tailed)	.004	.
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed).

Based on Table 4.19, Table 4.20, Table 4.21, and Table 4.22, the results show high correlations of thermal comfort, acoustics, lighting, and Indoor Air Quality (IAQ) between the BUS and EEBEQ result. A near to perfect significant correlation was found between thermal comfort (BUS) and thermal comfort (EEBEQ) (0.702). Meanwhile, acoustics (BUS) are significantly correlated with acoustics (EEBEQ) (0.476). On the other hand, lighting (BUS) and lighting (EEBEQ) have a correlation coefficient of 0.622, and finally Indoor Air Quality (BUS) and Indoor Air Quality (EEBEQ) have a correlation coefficient of 0.619. Thus, Building B shows good IEQ correlation between BUS and EEBEQ.

4.8.4.2 Building C

Table 4.23: Correlation of thermal comfort – Building C

		Thermal Comfort (BUS)	Thermal Comfort (EEBEQ)
Thermal Comfort (BUS)	Pearson Correlation	1	.484(**)
	Sig. (2-tailed)	.	.002
	N	54	37
Thermal Comfort (EEBEQ)	Pearson Correlation	.484(**)	1
	Sig. (2-tailed)	.002	.
	N	37	37

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.24: Correlation of acoustics – Building C

		Acoustics (BUS)	Acoustics (EEBEQ)
Acoustics (BUS)	Pearson Correlation	1	.501(**)
	Sig. (2-tailed)	.	.002
	N	54	37
Acoustics (EEBEQ)	Pearson Correlation	.501(**)	1
	Sig. (2-tailed)	.002	.
	N	37	37

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.25: Correlation of lighting – Building C

		Lighting (BUS)	Lighting (EEBEQ)
Lighting (BUS)	Pearson Correlation	1	.275
	Sig. (2-tailed)	.	.099
	N	54	37
Lighting (EEBEQ)	Pearson Correlation	.275	1
	Sig. (2-tailed)	.099	.
	N	37	37

Table 4.26: Correlation of Indoor Air Quality (IAQ) – Building C

		IAQ (BUS)	IAQ (EEBEQ)
IAQ (BUS)	Pearson Correlation	1	.406(*)
	Sig. (2-tailed)	.	.013
	N	54	37
IAQ (EEBEQ)	Pearson Correlation	.406(*)	1
	Sig. (2-tailed)	.013	.
	N	37	37

* Correlation is significant at the 0.05 level (2-tailed).

Based on Table 4.23, Table 4.24, Table 4.25, and Table 4.26, the results of the correlation between BUS and EEBEQ for Building C show high correlations for thermal comfort, acoustics, and Indoor Air Quality (IAQ). The thermal comfort (BUS) and thermal comfort (EEBEQ) have a correlation coefficient of 0.484, acoustics (BUS) and acoustics (EEBEQ) scored 0.501 for the correlation and Indoor Air Quality (BUS) and Indoor Air Quality (EEBEQ) have a correlation coefficient of 0.406. The lighting criteria for BUS and EEBEQ show no correlation, though thermal comfort, acoustics and Indoor Air Quality (IAQ) have recorded a high correlation between BUS and EEBEQ. As shown in Table 4.27 and Table 4.28, this might due to the confusion of the question in BUS by dividing the questions regarding to glare into glare from sun and sky and glare from lights, occupants could be confused by the word used and have made different judgment. The mean score for glare from the sun for BUS is only 3.0185 and the similar question in EEBEQ has a 4.2432 mean score,. The result from EEBEQ was correlated with the real condition of the building throughout the research carried out and some of the respondents had complained about the glare problems in the building and the building's owner have to install the additional shading in order to reduce glare caused by sunlight as shown in Figure 4.32.

Table 4.27: Descriptive analysis of lighting (EEBEQ) – Building C

	N	Minimum	Maximum	Mean
The natural daylight in the office building is sufficient for you to execute your work	37	3.00	7.00	5.0811
The position of the window in the office building is suitable in providing maximum daylight	37	3.00	7.00	5.2162
Do you agree that additional artificial light (eg. desk lamp) is needed while you are working	37	1.00	5.00	3.2973
Are you often interrupted by the glare/reflection caused by natural daylight while working	37	2.00	6.00	4.2432
Are the artificial lights in the office building not efficient	37	1.00	5.00	3.1892
The artificial lights in the office building are not often functioning	37	1.00	5.00	2.8919
As an occupant in the office building do you agree that artificial lightings are often used by you and your colleagues	37	1.00	5.00	3.6486
Do you agree that the current control system doesn't work according to your will	37	1.00	5.00	3.2432
Do you agree that a good control system contributes better lighting	37	3.00	7.00	5.1351
The artificial lighting control system is often down.	37	1.00	5.00	3.2162
The arrangement of cubicle/working table (allowing light to permit into your workplace)	37	3.00	7.00	5.0000
The types of working table you are using do not obstruct daylight but permit sufficient daylight while you are working	37	3.00	7.00	4.7027
Valid N (listwise)	37			

Table 4.28: Descriptive analysis of lighting (BUS) – Building C

	N	Minimum	Maximum	Mean
Natural light	54	2.00	6.00	4.0741
Glare from sun and sky	54	2.00	5.00	3.0185
Artificial light	54	1.00	6.00	3.5185
Glare from lights	54	1.00	5.00	3.0185
Valid N (listwise)	54			

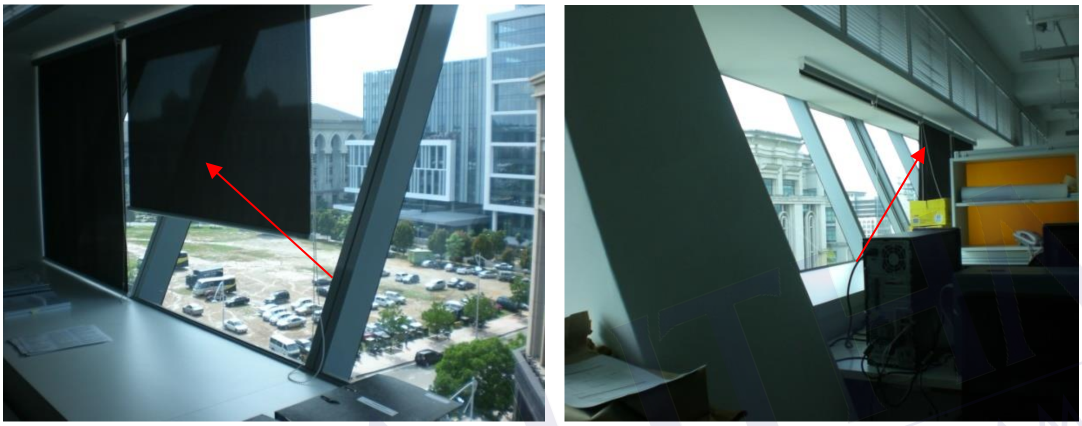

Figure 4.32: Additional blinds install after building occupancy.

Although there are some of the IEQ criteria from BUS and EEBEQ that do not show any correlation, there are still many of IEQ criteria that have high correlation with the BUS. Hence, the results indicated that the EEBEQ has statistically significant criterion validity.

4.8.5 Construct validity analysis

The construct validity of EEBEQ was analyzed by correlating it with the overall satisfaction question from BUS. The results of the correlation are shown in Table 4.29, Table 4.30 and Table 4.31.

Table 4.29: Correlation with overall satisfaction question from BUS – Building A

		Overall (BUS)	Overall (EEBEQ)
Overall (BUS)	Pearson Correlation	1	.439(**)
	Sig. (2-tailed)	.	.001
	N	54	54
Overall (EEBEQ)	Pearson Correlation	.439(**)	1
	Sig. (2-tailed)	.001	.
	N	54	54

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.30: Correlation with overall satisfaction question from BUS – Building B

		Overall (BUS)	Overall (EEBEQ)
Overall (BUS)	Pearson Correlation	1	.475(*)
	Sig. (2-tailed)	.	.034
	N	20	20
Overall (EEBEQ)	Pearson Correlation	.475(*)	1
	Sig. (2-tailed)	.034	.
	N	20	20

* Correlation is significant at the 0.05 level (2-tailed).

Table 4.31: Correlation with overall satisfaction question from BUS – Building C

		Overall (BUS)	Overall (EEBEQ)
Overall (BUS)	Pearson Correlation	1	.470(**)
	Sig. (2-tailed)	.	.003
	N	37	37
Overall (EEBEQ)	Pearson Correlation	.470(**)	1
	Sig. (2-tailed)	.003	.
	N	37	37

** Correlation is significant at the 0.01 level (2-tailed).

The overall satisfaction (BUS) and overall satisfaction (EEBEQ) for Building A were correlated at 0.439. For Building B, the overall satisfaction (BUS) and overall satisfaction (EEBEQ) were correlated at 0.475, meanwhile, the overall satisfaction (BUS) and the overall satisfaction (EEBEQ) for Building C were correlated at 0.470. The high correlation with the overall questions from BUS indicated that EEBEQ has high construct validity. EEBEQ has high consistency in providing reliable and validated information from building.

4.8.6 Comparison of overall comfort with sustainable building rating tools score

In this section, the results of the overall comfort will be compared with the sustainable building rating score of case study buildings. Green Building Index (GBI) was selected because all three case study buildings were rated by GBI and comparison between the buildings could only be made by selecting the same sustainable building rating tools.

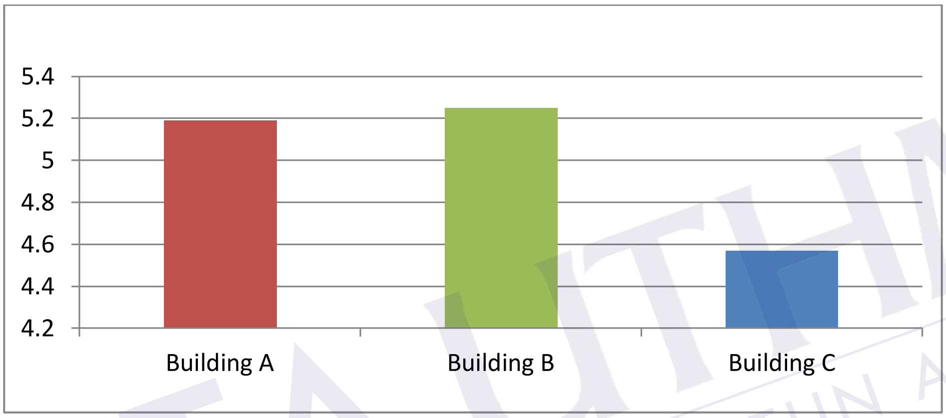

Figure 4.33: Overall comfort mean scores for case study buildings

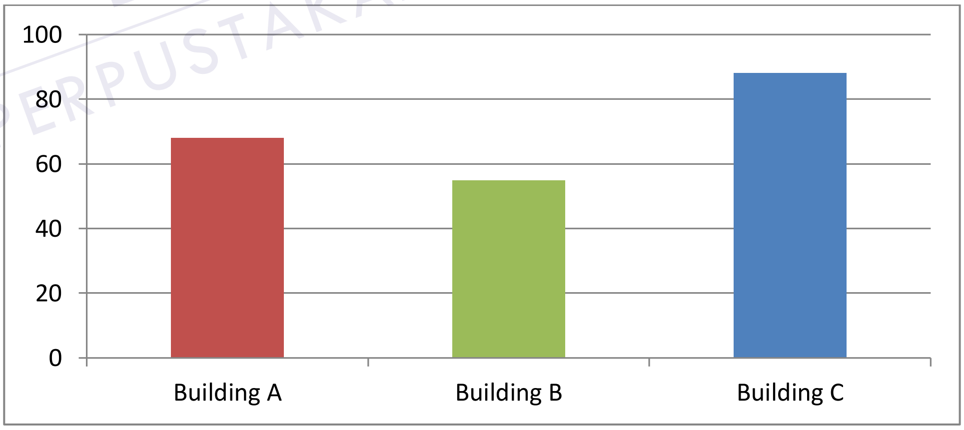

Figure 4.34: GBI scores for case study buildings

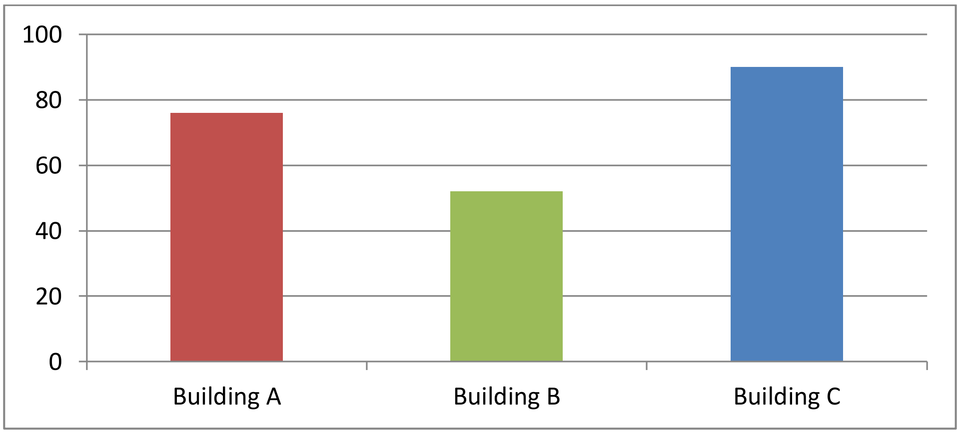

Figure 4.35: GBI (IEQ) scores for case study buildings

Based on Figure 4.33, Building B scores the highest mean value with 5.25 means score compared to other buildings. This is followed by Building A with a mean score of 5.19 and Building C with the lowest mean score among the case study buildings which is 4.57. The result implicates that occupants from Building B have the highest satisfaction level of the building's overall comfort, followed by Building A and Building C which has the least satisfaction level among the case study buildings. Although Building C has the lowest satisfaction level among the case study buildings, its GBI score as shown in Figure 4.34 is the highest compared to the other two case study buildings, Building C gets a GBI platinum with high score in the IEQ category (Figure 4.35). The low satisfaction of building's overall comfort for Building C could be due to occupants having high expectation on Building C which has obtained GBI Platinum and Green Mark Platinum certified. Besides that, the factor such as no window blinds and window shades plate and window mirror lightshelf on the outside of the building as shown in Figure 4.36 could also affect the thermal comfort of the building

Figure 4.36: Window without blinds and exterior of building without shades plate

Some respondents commented that they feel uncomfortably hot while working in the building. Other than that, factors such as lack of light reflective ceiling (Figure 4.37) might also affect the lighting condition in the building.

Figure 4.37: No reflective ceiling features reduce the emitting of natural daylight

The lighting condition in Building C especially the workplace area is dark in some area as shown in Figure 4.38 when the artificial lights are turned off. This situation is correlated with the result from EEBEQ where most of the respondents (4.6 mean score) agreed that they still can feel the heat of the sun coming from outside of the building while working in the office as shown in Table 4.32.

Figure 4.38: Office area is dark when lights are turned off during daytime

Table 4.32: Descriptive analysis of window blinds/shades and window (EEBEQ) – Building C

	N	Minimum	Maximum	Mean
I can still feel the heat of the sun coming through the window although the window blinds in my working area have been pulled down	37	1.00	6.00	3.1351
I can still feel the heat of the sun coming through the window while sitting or standing near to the windows that have window shades	37	2.00	7.00	4.5676
The current window blinds control system doesn't work according to your desire	37	2.00	6.00	4.0541
Do you agree that a good window blind control system contributes better thermal comfort	37	3.00	7.00	5.3243
The window blinds control system is often down	37	1.00	5.00	2.9189
I have to pull down window blinds in order to reduce the heat coming from outside of the building	37	2.00	7.00	4.7568
There are too many windows in your workplace and causing you to feel uncomfortable due to the heat of the sun	37	2.00	7.00	4.3243
The current window control system doesn't work according to your desire	37	1.00	6.00	3.3514
Do you agree that a good window control system contributes better thermal comfort	37	3.00	7.00	5.1622
The window control systems is often down	37	1.00	5.00	3.1892
Valid N (listwise)	37			

4.9 Summary

The collected data were analyzed using the methodology as stated in Chapter 3. Site visits had been conducted at the case study buildings in order to identify the application of energy-efficient components in the office building. Interview and observation were carried out during the site visit. Photos were taken and important information retrieved during the interview have been analyzed using information coding table and the data were further analyzed by summarizing the energy-efficient design components applied in the office building particularly for building built in hot and humid climatic region. After the identification of the main energy-efficient components, data gathering was conducted through the previous researches in order to collect and identify the problems of energy-efficient design which are affecting the occupants' comfort. EEBEQ was formed based on the information gathered from interviews, observation, site visits, and mapping of previous studies. The newly formed questionnaire – EEBEQ was later tested at the case study buildings. The data gathered from the questionnaire were analyzed using SPSS software, the content validity, construct validity and criterion validity of the questionnaire have been conducted, and the outcome are acceptable in terms of its validity. Croanbach's Alpha and test-retest reliability were carried and both of the tests show good reliability. A strong reliability and validity of the EEBEQ shows that it is suitable to be applied in all types of energy-efficient buildings built in hot and humid climatic regions such as Malaysia. At the end of the analysis, the results from the data analysis revealed that although a building has been certified by the sustainable building rating tools, yet the certification could not guarantee a good IEQ performance after the building is being used.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The research objectives have been achieved after the analysis of data has been carried out. The first objective is to propose an evaluation framework for the identification of problems which affect the occupants' comfort, the second objective is to determine the reliability and validity of the proposed evaluation framework, and the third objective is to analyze the occupants' comfort level of the energy-efficient (office) building.

Interview sessions have been carried out with four respondents which have been involved in the design stage of the energy-efficient buildings. Observations have been conducted at the case study buildings together with interviews. Meanwhile, the information gathered from the previous studies has been mapped and analyzed based on the Indoor Environmental Quality (IEQ) criteria and energy-efficient and passive design components. The gathered information was used in the formation of Energy-Efficient Building Environmental Quality Evaluation Framework.

At the final stage, the Energy-Efficient Building Environmental Quality Evaluation Framework was tested at the case study buildings. The validity and reliability of the Energy-Efficient Building Environmental Quality Evaluation Framework was measured using SPSS software with sociological principles and test procedures for validation. At the end of the research, a validated Energy-Efficient Building Environmental Quality Evaluation Framework was successfully developed.

The finding of the data analysis process has contributed to the recommendation of future study. The information used for the recommendation of future study is based on the result from the data analysis.

5.2 Objective 1

To propose an evaluation framework for the identification of problems which affect the occupants' comfort.

The result of the study from interviews and observation process show that the energy-efficient components applied in the case study buildings can be categorized into passive design and energy-efficient design components as shown in Figure 5.1. The energy-efficient components identified in the case study buildings are met with the building design requirement in hot humid climatic regions. Most of the design efforts are aimed to reduce heat gained from the surrounding. Energy reduction in the building are focused in the cooling aspect; this is because building in hot and humid climate tends to consume a lot of energy for the cooling purposes.

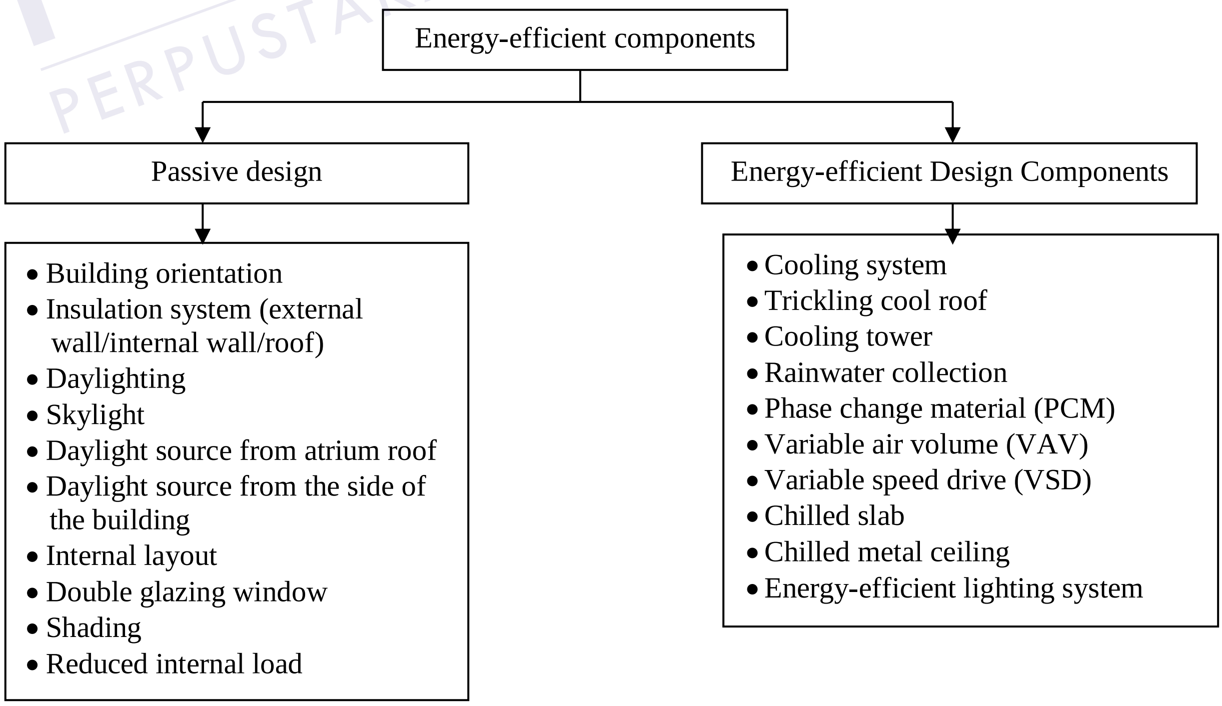

Figure 5.1: Energy-efficient components

The result from the mapping of previous studies have successfully identified that there are 49 commonly occurring problems at the energy-efficient buildings which affect the occupants’ comfort or IEQ criteria. The identified energy-efficient design problems affecting occupants’ comfort are air conditioning system, natural ventilation system, window, radiant ceiling cooling system, radiant floor cooling system, artificial lighting, window shades, office layout, envelope tightness, and mechanical ventilation system. The energy-efficient design problems can eventually affect the buildings’ IEQ. In the end, 4 main IEQ criteria have been identified; thermal comfort, indoor air quality (IAQ), lighting, and acoustics. The findings also show that thermal comfort has the highest rank compared to other IEQ criteria, followed by acoustics, lighting, and IAQ.

5.3 Objective 2

To determine the reliability and validity of the proposed evaluation framework.

The newly constructed Energy-Efficient Building Environmental Quality Evaluation Framework was sent to the experts from sustainable building fields for validation purpose. The respondents were asked to fill out the validation form in order to rank the question of the Energy-Efficient Building Environmental Quality Evaluation Framework according to its relevance. The content validation process was conducted using Lawshe Method and the result show that all questions have Content Validity Ratio (CVR) between 0.6 and 1.0, and the CVI value for the Energy-Efficient Building Environmental Quality Evaluation Framework is 0.95, showing high content validity of the questionnaire.

After the content validation analysis, the Energy-Efficient Building Environmental Quality Evaluation Framework was distributed to the occupants from the case study buildings as identified earlier. This process was carried out in order to measure the reliability, construct validity and criterion validity of Energy-Efficient Building Environmental Quality Evaluation Framework. The reliability of Energy-Efficient Building Environmental Quality Evaluation Framework was measured using Cronbach's Alpha. Building A, Building B, and Building C, have Cronbach's Alpha of 0.7326, 0.7065, and 0.7440 respectively, which show high reliability value. For test-retest reliability, all questions have obtained good intra-class correlation coefficient (ICC) test, with the ICC value ranging from 0.51 to 1.00. The final result of the reliability analysis shows that the Energy-Efficient Building Environmental Quality Evaluation Framework has high reliability.

For criterion validity analysis, Building B has scored perfect criterion validity for Energy-Efficient Building Environmental Quality Evaluation Framework when it is compared with the result from BUS. Meanwhile, Building A and Building C have only scored rather good criterion validity. This is because the lighting result from the Energy-Efficient Building Environmental Quality Evaluation Framework of Building A, and Building C do not correlate with the similar criteria from BUS. However other IEQ criteria have high correlation with BUS. Overall, the criterion validity of Energy-Efficient Building Environmental Quality Evaluation Framework after being tested at the case study buildings show good validity. This means that the result from Energy-Efficient Building Environmental Quality Evaluation Framework can accurately measure the IEQ criteria of energy-efficient buildings.

Furthermore, the results of the construct validity analysis show perfect construct validity score for Energy-Efficient Building Environmental Quality Evaluation Framework. The Energy-Efficient Building Environmental Quality Evaluation Framework result was also correlated with the overall comfort question from BUS. The findings show that the Energy-Efficient Building Environmental Quality Evaluation Framework has good correlation with BUS, thus the Energy-Efficient Building Environmental Quality Evaluation Framework questionnaire could be summarized as having a good reliability and validity for measuring the occupants' comfort in energy-efficient building in terms of IEQ criteria.

5.4 Objective 3

To analyze the occupants' comfort level of the energy-efficient (office) building.

Occupants from the case study buildings are generally indicating low satisfaction towards building's lighting condition where the question regarding to window position in providing daylight and glare problems score the mean value of 3.50 and 4.24, which means majority of the occupants taking the survey are generally dissatisfied with the lighting condition of the building. The result of this research shows that, the sustainable building rating tools are not effective enough in ensuring high performance energy-efficient building especially in terms of IEQ. Building C with the certification of sustainable building rating tools, GBI – Malaysia and Green Mark Singapore, has low satisfaction in the overall comfort. Occupants from Building C are also facing glare problems compared to occupants from Building A and B.

Furthermore, the results show that the validated Energy-Efficient Building Environmental Quality Evaluation Framework is able to identify the inefficiency of energy-efficient design after building occupancy. Although Building C obtains GBI platinum and Green Mark platinum certificate, the building occupants have ranked their low satisfaction towards the building's IEQ performance. The findings are supported by the fact that additional features such as window blinds as shown in Figure 5.1 were added after the building is being used. Building A and Building B also show the similar trend, and additional fans as shown in Figure 5.1 and Figure 5.2 have been installed for cooling purpose in the two case study buildings.

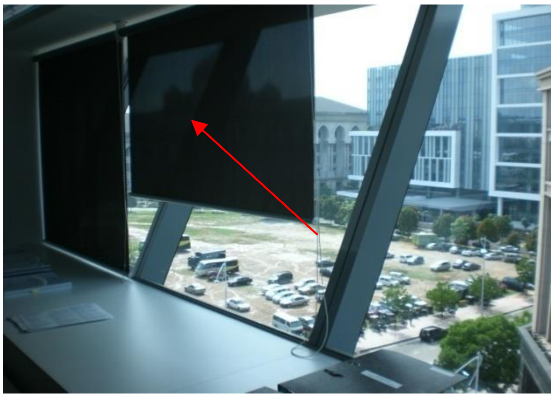

Figure 5.1: Additional window blinds – Building C

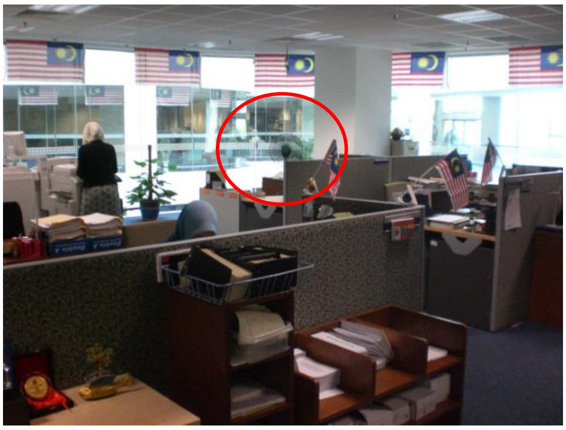

Figure 5.2: Additional fans – Building A

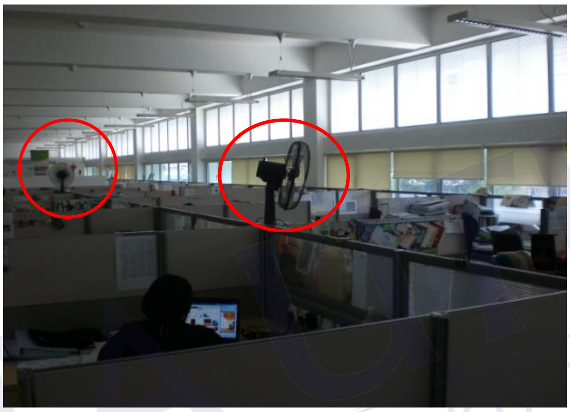

Figure 5.3: Additional fans – Building B

In summary, Energy-Efficient Building Environmental Quality Evaluation Framework has been proven to be able to identify the design problems and prevent repeating mistakes in filling the gap of sustainable building rating tools which are not sufficient enough in ensuring high performance energy-efficient buildings especially in terms of IEQ.

5.5 Research limitations

Although the research has achieved its aims, there are some unavoidable limitations encountered while executing the study. Since there are limited qualified energy-efficient buildings in Malaysia which have been used exceeding 1 year and above, thus this study have been conducted at the 3 case study buildings which have high energy-efficiency features and low energy consumption. Although there are only three case study buildings have been understudied, the high efficiency of the buildings could compensate the limitations.

Besides that, the Energy-Efficient Building Environmental Quality Evaluation Framework can only be used to study the IEQ performance of office building. Although it can only be used to study the office building, the increasing awareness of the employers about how the working performance can be affected by the building's IEQ are setting the trend to improve the occupants' comfort in office building. Thus the Energy-Efficient Building Environmental Quality Evaluation Framework can certainly contribute to better indoor environment in the workplace.

The Energy-Efficient Building Environmental Quality Evaluation Framework is also limited to the office building in hot and humid climatic regions such as Malaysia. The developments of energy-efficient buildings in the countries situated in hot and humid climatic regions are mostly at the infant stage. Thus, it is important to have a survey framework and building performance analysis model suiting the architectural features in buildings for the hot and humid climatic regions.

5.6 Recommendations for future research

The findings from the research have generated some consideration of important aspects in future research. The recommendations are stated as below:

(a) The research could be extended to the residential type building, and the information gathered from various types of buildings could contribute to better development of energy-efficient building.

(b) Greater building samples are possible for future research; this is due to the increase of energy-efficient building development in the future.

(c) The Energy-Efficient Building Environmental Quality Evaluation Framework could be transformed into more sophisticated electronic version in order to reduce the hassle during data collection process and save time.

(d) The Energy-Efficient Building Environmental Quality Evaluation Framework could be extended in terms of its usage to other climatic regions by making some changes that suit the climate condition such as cold climate regions.

5.7 Summary

The outcomes of the research have successfully devised a new evaluation framework – Energy-Efficient Building Environmental Quality Evaluation Framework for the measurement of energy-efficient buildings' IEQ. The newly designed evaluation framework has been validated and proven of its reliability. Thus it is shown that the evaluation framework is able to identify and determine the comfort level of the occupants in the office building. The research has also found that there are still a lot of problems faced by the energy-efficient buildings, particularly the IEQ. More research is needed in order to overcome the problems faced by the users of these energy-efficient building. The evaluation of IEQ after occupancy is crucial in getting the feedback from the occupants after the building is being used. In conclusion, building owners, occupants, and peoples involved at the design stage of the building need to have a healthy communication in order to fill the gap between the actual building performance and the intended performance.

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APPENDIX

Energy-efficient Building Environmental Quality Questionnaire (EBEQ^2)

This survey is for master research project. The aim of this survey is to collect data regarding the occupant perception towards energy-efficient design. Information provided by respondents in this survey will be ***STRICTLY CONFIDENTIAL***.

Thank you for your kind cooperation.

If you have any queries please contact: Ng Ban Huat.
Tel.: 016-6048535 email:ngbanhuat@hotmail.com

Section A: General Information

Please kindly put a tick (√) in the appropriate box.
Sila tandakan (√) dalam kotak yang disediakan.

Gender/***Jantina***: Male/***Lelaki*** ☐ Female/***Perempuan*** ☐

Age/***Umur***: > 20 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ <50 ☐

Education level/***Tahap Pendidikan***:
- Primary (Std. 1-6)/ ***Rendah (Darjah. 1-6)*** ☐
- Secondary (Form 1-5)/***Menengah (Tigkatan: 1-5)*** ☐
- Pre-U (Form 6/equivalent)/ ***Pra-U (Tingkatan 6/setara denganya)*** ☐
- University/college (Diploma-1st Degree)/ ***Universiti/kolej (Diploma-Ijazah pertama)*** ☐
- Post Graduate (Master-Phd)/ ***Pasca Siswazah (Ijazah-Phd)*** ☐

Occupational level/***Tahap Pekerjaan***:
- Administrative/***Pentadbiran*** ☐
- Management/ ***Pengurusan*** ☐
- Executive/ ***Eksekutif*** ☐
- Secretarial/ ***setiausaha*** ☐
- Technical/***Teknikal*** ☐

How many years have you been working in this building?
Berapa tahun anda telah bekerja di dalam bangunan ini?

____

Which floor is your workplace?
Anda bekerja di tingkat berapa?

____

How many colleagues are working in the same area with you?
Berapa ramai pekerja yang bekerja di tempat/tingkat yang sama dengan anda?

____

Description of your workplace/***Deskripsi tempat kerja anda***
- Facing the window/ ***menghadap tingkap*** ☐
- Backing the window/ ***membelakang tingkap*** ☐
- Side to window/ ***bersebelahan dengan tingkap*** ☐
- No window around/ ***tidak mempunyai tingkap*** ☐

Section B: Indoor Environmental Quality (IEQ) criteria

Thermal comfort/ *Keselesaan termal*

Window blinds/shades/ *Pengadang/tirai tingkap*

(a) I can still feel the heat of the sun coming through window although the window blinds in my working area has been pulled down./ ***Saya masih boleh rasa panas dari luar bangunan walaupun tirai tingkap telah diturunkan.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(b) I can still feel the heat of the sun coming through window while sitting or standing near to the windows that have window shades./ ***saya masih boleh rasa panas dari luar tingkap apabila berdiri atau duduk dekat dengan tingkap yang dipasang dengan pengadang.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(c) The current window blinds control system doesn't work according to your desire./ ***Sistem kawalan tirai tingkap tidak berfungsi sepertimana yang anda inginkan.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(d) Do you agree a good window blinds control system contribute better thermal comfort? ***Adakah sistem kawalan tirai tingkap yang cekap akan memberikan keselesaan termal yang lebih baik?***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(e) The window blinds control systems often went down./***Sistem kawalan tirai tingkap selalu rosak.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

Window/*Tingkap*

(a) I have to pull down window blinds in order to reduce the heat coming from outside of the building while working in a room with closed windows./ ***Saya perlu menurunkan tirai tingkap untuk mengurangkan rasa panas di dalam bilik yang dengan tingkap yang tertutup.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(b) There are too many windows in your workplace and causing you to feel uncomfortable due to the heat of the sun. ***Terdapat banyak tingkap di tempat kerja anda dan menyebabkan anda rasa panas.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(c) The current window control system doesn't work according to your desire?/ ***Sistem kawalan tingkap tidak berfungsi sepertimana yang anda inginkan?***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(d) Do you agree a good window control system contribute better thermal comfort?/ ***Adakah sistem kawalan tingkap yang cekap akan memberikan keselesaan termal yang baik .***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(e) The window control systems often went down?./ ***Sistem kawalan tingkap selalu rosak.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

Room air-conditioning unit/ *Unit penghawa dingin*

(a) The air conditioning system does not provide comfortable room temperature./***Sistem penghawa dingin tidak memberikan suhu bilik yang selesa?***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(b) The air-conditioning systems in the office often went down./ ***Sistem penghawa dingin di bangunan ini selalu rosak.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(c) Do you agree the current air-conditioning control system doesn't work according to your desire?/ ***Sistem kawalan penghawa dingin tidak berfungsi sepertimana yang anda inginkan.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(d) Do you agree a good air-conditioning control system contribute better thermal comfort?/ ***Adakah sistem kawalan penghawa dingin yang cekap akan memberikan keselesaan termal yang baik***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(e) The air-conditioning control systems often went down./ ***Sistem penghawa dingin selalu rosak.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

Radiant cooling system (floor slab unit, chilled metal ceiling)

(a) The floor surface in the office is always slippery (Not caused by cleaning chore)/***Permukaan lantai pejabat adakala licin tidak disebabkan oleh kerja pembersihan.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(b) Part of the ceiling in the office looks moisture and causing water drop (Not caused by rainwater/pipe leaking)./ ***Permukaan siling pejabat kelihatan basah tidak disebabkan hujan/kebocoran paip)***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(c) Most of the staff including you feel radiant asymmetry (local cold discomfort in the arm-hand and the leg-foot regions) while working in office?/ ***Adakah anda berasa kesejukan pada banhagian tangan dan kaki apabila berada dalam pejabat pada masa yang panjang***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

Ventilation system/ *Sistem pengudaraan*

(a) The ventilation system in the office building performing well/ ***Sistem pengudaraan di pejabat berfungsi dengan baik.***

Strongly Disagree/ ***Sangat tidak setuju*** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | *Strongly Agree/* ***Sangat setuju***

(b) Do you agree a good ventilation system contribute better thermal comfort?/ ***Adakah sistem pengudaraan yang baik memberikan keselesaan termal yang baik?***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(c) The ventilation system in the office building often went down./ ***Sistem pengudaraan di bangunan ini selalu rosak?***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(d) Do you agree the current ventilation control system doesn't work according to your desire?/ ***Sistem pengudaraan selalu rosak.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(e) Do you agree a good ventilation control system contribute better thermal comfort?/ ***Adakah sistem pengudaraan yang cekap akan memberikan keselesaan termal yang baik.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(f) The ventilation control systems often went down./ ***Sistem pengudaraan selalu rosak.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Acoustics/ ***Akustik***

Office Layout/***Susun atur pejabat***
(a) Too much of open space in the working area can cause distractions while working when others are making their conversation./ ***Tempat kerja yang terbuka mudah memberikan gangguan jika orang lain melakukan perbualan ketika anda sedang bekerja.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) Too much of glass material (partition/window) causing echo effect./ ***Bahan cermin (partition/tingkap) yang banyak menyebabkan kesan gema?***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Room air-conditioning unit/ ***Unit penghawa dingin***
(a) The air-conditioning unit causing unwanted noise while in use/ ***Unit penghawa dingin mengeluarkan bunyi bising semasa operasi.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Mechanically ventilation system/ ***Sistem pengudaraan mekanikal***
(a) The mechanical ventilation system causing unwanted noise while in use/ ***Sistem pengudaraan mekanikal mengeluarkan bunyi bising semasa operasi.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Lighting/ ***Pencahayaan***

Orientation/Daylighting (window/skylight)
(a) The natural daylight in the office building sufficient for you to execute your work./ ***Tahap cahaya di tempat anda adalah cukup untuk anda menjalakan tugas seharian.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) The position of the window in the office building suitable in providing maximum daylight./ ***Tingkap di tempat kerja anda memberikan sumber cahaya yang cukup.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(c) Do you agree that additional artificial light (eg. Desk lamps) is needed while you are working?/ ***Adakah anda menggunakan lampu tambahan seperti lampu meja semasa and menjalankan tugas anda.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(d) Do you often interrupted by the glare/reflection caused by natural daylight while working?/ ***Semasa mejalankan tuga anda adakah anda diganggu oleh masalah silau dari cahaya luar.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Artificial lighting system/***Sistem cahaya elektrik***
(a) Does the artificial lights in the office building not efficient enough?./ ***Adakah tahap cahaya lampu elektrik di tempat anda tidak cekap.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) The artificial lights in the office building are often not functioning./ ***Lampu cahaya elektrik dalam bangunan ini sentiasa rosak***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(c) As the occupants in the office building do you agree that artificial lightings are often used by you and your colleague while working?/ ***Sebagai seorang penghuni dalam bagunan ini adakah lapu cahaya elektrik selalu digunakan oleh anda dan rakan sekerja anda?.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(d) Do you agree the current control system doesn't work according to your will?/ ***Sistem kawalan lampu tidak berfungsi sepertimana yang anda inginkan.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(e) Do you agree a good control system contribute better lighting experience?./ ***Sistem kawalan lampu yang cekap memberikan keadaan pencahayaan yang baik.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(f) The artificial lighting control systems often went down./ ***Sistem kawalan lampu cahaya elektrik selalu rosak.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Office Layout/***Susun atur pejabat***
(a) The arrangement of cubicle/working table (allowing light to permit into your workplace)./ ***Pengaturan kubikel/meja kerja (memberikan cahaya sampai ke tempat kerja anda)***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) The types of working table you are using do not obstruct daylight but permitting sufficient daylight while you are working?/ ***Jenis meja kerja yang anda gunakan tidak menghalang sumber cahaya semasa anda menjalakan tugas anda.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Indoor Air Quality/ ***Kualiti udara***

Ventilation system/ ***Sistem pengudaraan***
(a) Your current workplace is stuffy?/ ***Tempat kerja anda pengap***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) Does your working area is affected by odor?/ ***Adakah tempat kerja anda mempunyai masalah bau yang tidak disenangi?***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Envelope tightness
(a) The doors which connect to the outside room/office building are often remaining unclosed/not fully closed/ ***Pintu yang berhubung dengan luar pejabat/bangunan sentiasa tidak tertutup/tutup sebahagian sahaja.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

(b) The windows connect to the outside room/office building is often remain unclosed/not fully closed?/ ***Tingkap yang berhubung dengan luar pejabat atau bangunan sentiasa tidak tertutup/tutup sebahagian sahaja.***
Strongly Disagree/ ***Sangat tidak setuju*** [1 | 2 | 3 | 4 | 5 | 6 | 7] *Strongly Agree/* ***Sangat setuju***

Thank you for your help

If you have further comments on the topics raise, please add them on a separate sheet.
Please leave the questionnaire in a prominent place, and it will be collected later today.

APPENDIX B1

Validation Form

Instruction: *Please read the questions in the questionnaire form (APPENDIX B) as attached, and rate the questionnaire by filling out this Validation Form***.**

Rank: ***A-Low Relevant***
B-Moderate Relevant
C-High Relevant

Section A: General Information	***Rank(A,B,C)***
1	☐ *A* ☐*B* ☐*C*
2	☐ *A* ☐*B* ☐*C*
3	☐ *A* ☐*B* ☐*C*
4	☐ *A* ☐*B* ☐*C*
5	☐ *A* ☐*B* ☐*C*
6	☐ *A* ☐*B* ☐*C*
7	☐ *A* ☐*B* ☐*C*
8	☐ *A* ☐*B* ☐*C*
Section B: problems causing the inefficiency of energy-efficient design in respect to occupants' comfort	***Rank(A,B,C)***
Thermal comfort ***1. Window blinds/shades*** *(a)*	☐ *A* ☐*B* ☐*C*
(b)	☐ *A* ☐*B* ☐*C*
(c)	☐ *A* ☐*B* ☐*C*
(d)	☐ *A* ☐*B* ☐*C*
(e)	☐ *A* ☐*B* ☐*C*

APPENDIX B2

Rank: ***A-Low Relevant***
B-Moderate Relevant
C-High Relevant

	Rank(A,B,C)
2. Window *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
(c)	☐ *A* ☐ *B* ☐ *C*
(d)	☐ *A* ☐ *B* ☐ *C*
(e)	☐ *A* ☐ *B* ☐ *C*
3. Room air-conditioning unit *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
(c)	☐ *A* ☐ *B* ☐ *C*
(d)	☐ *A* ☐ *B* ☐ *C*
(e)	☐ *A* ☐ *B* ☐ *C*
4. Radiant cooling system (floor slab unit, chilled metal ceiling) *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
(c)	☐ *A* ☐ *B* ☐ *C*

APPENDIX B3

Rank: ***A-Low Relevant***
B-Moderate Relevant
C-High Relevant

	Rank(A,B,C)
5. Ventilation system *(a)*	☐ *A* ☐*B* ☐*C*
(b)	☐ *A* ☐*B* ☐*C*
(c)	☐ *A* ☐*B* ☐*C*
(d)	☐ *A* ☐*B* ☐*C*
(e)	☐ *A* ☐*B* ☐*C*
(f)	☐ *A* ☐*B* ☐*C*
Air quality ***1. Ventilation system*** *(a)*	☐ *A* ☐*B* ☐*C*
(b)	☐ *A* ☐*B* ☐*C*
2. Envelope tightness *(a)*	☐ *A* ☐*B* ☐*C*
(b)	☐ *A* ☐*B* ☐*C*
Lighting ***1. Orientation/Daylighting (window/skylight)*** *(a)*	☐ *A* ☐*B* ☐*C*
(b)	☐ *A* ☐*B* ☐*C*
(c)	☐ *A* ☐*B* ☐*C*
(d)	☐ *A* ☐*B* ☐*C*
(e)	☐ *A* ☐*B* ☐*C*

APPENDIX B4

Rank: ***A-Low Relevant***
B-Moderate Relevant
C-High Relevant

	Rank(A,B,C)
2. Artificial lighting system *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
(c)	☐ *A* ☐ *B* ☐ *C*
(d)	☐ *A* ☐ *B* ☐ *C*
(e)	☐ *A* ☐ *B* ☐ *C*
(f)	☐ *A* ☐ *B* ☐ *C*
3. Office Layout *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
Acoustic ***1. Office Layout*** *(a)*	☐ *A* ☐ *B* ☐ *C*
(b)	☐ *A* ☐ *B* ☐ *C*
2. Room air-conditioning unit *(a)*	☐ *A* ☐ *B* ☐ *C*

APPENDIX B5

DATE:_____ /_____/ _____
NAME: ___________________________________
POSITION: __________________________________

YEARS OF EXPERIENCE IN YOUR RESPECTIVE FIELD: ____________________

In my opinion, I rank this questionnaire as

☐ *A – Low Relevant*

☐ *B – Moderate Relevant*

☐ *C – High Relevant*

Biodata/CV:
____
____
____
____
____
____
____
____

Note: Please return the completed validation form ***(APPENDIX A)*** to: (email address) ngbanhuat@hotmail.com

Thank you for taking the time to filling out this validation form, your cooperation is greatly appreciated.

Building Evaluation

This survey is being conducted to help with the design and planning of buildings and workplaces. The information collected will be treated as completely confidential by the survey team. Survey reports will use summaries of information and not reveal the identities of individuals.

Please answer for the study building only. Please fill in as many questions as you can. Write any further comments in the spaces provided or on a separate sheet.
Thank you for your help

Queries:
If you have any queries please get in touch with Ng Ban Huat.
Email: ngbanhuat@hotmail.com .

Background

Please note: We ask about age and sex because these are both relevant to people's needs in buildings. We ask for names so that we can follow up any matters that arise.

What is your age...? *Please tick* Under 30 [1] [2] 30 or over

... and your sex? *Please tick* Male [1] [2] Female

Please give your name ... [*Surname, then first name*]

... and Department [*Department*]

Is this building your normal base? *Please tick* Yes [1] [2] No

If No, which is ... ? [*Normal base if not this building*]

Please tick if you are an outside contractor: Contractor [1]

Is your office or work area ...? *Please tick*
- [1] Normally occupied by you alone
- [2] Shared with 1 other
- [3] Shared with 2-4 others
- [4] Shared with 5-8 others
- [5] Shared with more than 8 others

Do you sit next to a window at your normal workspace? *Please tick* Yes [1] [2] No

How long have you worked in this building? *Please tick* Less than a year [1] [2] A year or more

How long have you worked in your present work area? *Please tick* Less than a year [1] [2] A year or more

How many days do you spend in the building in a normal working week? [*Days per week in building*]

How many hours per day do you spend in the building on a normal working day? [*Hours per day in building*]

How many hours per day do you spend at your desk or normal work area on a normal working day? [*Hours per day at desk*]

How many hours per day do you normally spend working with a computer screen (VDU)? [*Hours per day at VDU*]

The building overall

Building design — All things considered, how do you rate the building design overall?
Please tick Unsatisfactory [1] [2] [3] [4] [5] [6] [7] Satisfactory
[*Comments about design overall*]

Needs — In the building as a whole, do the facilities meet your needs?
Please tick Unsatisfactory [1] [2] [3] [4] [5] [6] [7] Satisfactory
[*Comments about needs overall*]

Space — In the building as a whole, do you think that space is used ...?
Please tick Ineffectively overall [1] [2] [3] [4] [5] [6] [7] Effectively overall

Image — How do you rate the image that the building as a whole presents to visitors...?
Please tick Poor [1] [2] [3] [4] [5] [6] [7] Good

Safety — How do you rate your personal safety in and around the building ...?
Please tick Poor [1] [2] [3] [4] [5] [6] [7] Good

Cleaning — How do you rate the cleaning ...?
Please tick Unsatisfactory [1] [2] [3] [4] [5] [6] [7] Satisfactory

Availability of meeting rooms
Please tick Unsatisfactory [1] [2] [3] [4] [5] [6] [7] Satisfactory
[*Comments about meeting rooms*]

Suitability of storage arrangements
Please tick Unsatisfactory [1] [2] [3] [4] [5] [6] [7] Satisfactory
[*Comments about storage*]

Your work

Please briefly describe the work that you carry out in this building ...?
[*Work description*]

Your work requirements

Specifically, for the work that you carry out, how well do the office facilities meet your needs ...?
Please tick Very poorly [1] [2] [3] [4] [5] [6] [7] Very well

Please give examples of things which can hinder effective working ...?
[*Hinder*]

... and examples of things which usually work well ...?
[*Work well*]

Your desk or work area

Furniture — How do you rate the usability of the furniture provided at your desk or normal work area ...?
Please tick Very poor [1] [2] [3] [4] [5] [6] [7] Very good

Space at desk — Do you have enough space at your desk or normal work area ...?
Please tick Too little [1] [2] [3] [4] [5] [6] [7] Too much

[*Comments about your desk or work area*]

Comfort This section asks how comfortable you find the building.

How would you describe typical working conditions in your normal work area? These questions refer to conditions *all year round*. If there are seasonal variations which affect your ratings, please give more details in the comments box.

Please tick your rating on each scale

Temperature

Uncomfortable	1	2	3	4	5	6	7	Comfortable
Too hot	1	2	3	4	5	6	7	Too cold
Stable	1	2	3	4	5	6	7	Varies during the day

Air

Still	1	2	3	4	5	6	7	Draughty
Dry	1	2	3	4	5	6	7	Humid
Fresh	1	2	3	4	5	6	7	Stuffy
Odourless	1	2	3	4	5	6	7	Smelly

Conditions overall

Unsatisfactory overall	1	2	3	4	5	6	7	Satisfactory overall

Comments about thermal comfort and ventilation, including any seasonal variations that may affect your ratings.

Noise How would you describe noise in your normal work area?
This question refers to conditions all year round

Please tick your rating on each scale

Noise overall	Unsatisfactory	1	2	3	4	5	6	7	Satisfactory
Noise from colleagues	Too little	1	2	3	4	5	6	7	Too much
Noise from other people	Too little	1	2	3	4	5	6	7	Too much
Other noise from inside	Too little	1	2	3	4	5	6	7	Too much
Noise from outside	Too little	1	2	3	4	5	6	7	Too much

Please estimate how you are affected by unwanted interruptions ...

Unwanted interruptions	Not at all	1	2	3	4	5	6	7	Very frequently

Comments about noise and its sources

Lighting How would you describe the quality of the lighting in your normal work area? This question refers to conditions all year round

Please tick your rating on each scale

Lighting overall	Unsatisfactory	1	2	3	4	5	6	7	Satisfactory
Natural light	Too little	1	2	3	4	5	6	7	Too much
Glare from sun and sky	None	1	2	3	4	5	6	7	Too much
Artificial light	Too little	1	2	3	4	5	6	7	Too much
Glare from lights	None	1	2	3	4	5	6	7	Too much

Comments about lighting conditions

Overall comfort All things considered, how do you rate the overall comfort of the building environment?

Please tick

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Comments about comfort

Productivity at work

Please estimate how you think your productivity at work is increased or decreased by the environmental conditions in the building?

Please tick one point on the scale

Productivity Decreased by ...	- 40% or less	-30%	-20%	-10%	0	+10%	+20%	+30%	+40% or more	Productivity Increased by ...
	1	2	3	4	5	6	7	8	9	

Comments about productivity

Health Do you feel less or more healthy when you are in the building?

Please tick

Less healthy	1	2	3	4	5	6	7	More healthy

Comments about health

Personal control How much control do you personally have over the following aspects of your working environment...?

Please tick each scale

Importance of control Please tick if important to you

Heating	No control	1	2	3	4	5	6	7	Full control	1
Cooling	No control	1	2	3	4	5	6	7	Full control	1
Ventilation	No control	1	2	3	4	5	6	7	Full control	1
Lighting	No control	1	2	3	4	5	6	7	Full control	1
Noise	No control	1	2	3	4	5	6	7	Full control	1

Response to problems Have you ever made requests for changes to the heating, lighting, ventilation or air-conditioning/cooling (if you have it)...?

Please tick

Yes [1] [2] No

Please give brief details

If yes, how satisfied in general were you with the ...?

Speed of response

Please tick

Unsatisfactory overall [1] [2] [3] [4] [5] [6] [7] Satisfactory overall

Effectiveness of response

Please tick

Unsatisfactory overall [1] [2] [3] [4] [5] [6] [7] Satisfactory overall

Effect on behaviour Do you change your behaviour because of conditions in the building ...?

Please tick

Yes [1] [2] No

If Yes, please give examples. Please note: all responses are treated as completely confidential. Identities of individuals are never revealed.

Travel to work

Please estimate your journey times ...

Journey to work		Time Hours : minutes	**Journey home**		Time Hours : minutes
Best case	Journey to work		Best case	Journey home	
Normal	Journey to work		Normal	Journey home	
Worst case	Journey to work		Worst case	Journey home	

Post or zip code What is your home post or zip code (or the place where you normally start your journey to work if not home) ...? Postcode

Mode of travel

For your **journey to work only**, how do you normally travel ...?

	Please tick those which apply	**Main mode** *Please tick one*
Walk	1	1
Cycle	1	1
Bus	1	1
Train	1	1
Car (as driver)	1	1
Car (lift or car share passenger)	1	1
Motor cycle (solo)	1	1
Motor cycle (as passenger)	1	1
Tram / Trolleybus	1	1
Ferry	1	1
Other (please specify)	1	1

Main mode *means the journey mode by which you travel the longest distance.*

Please specify if Other

Have you any comments or observations on your journeys to work and home, especially with respect to how they affect your work ...?

Comments on journeys to work and home from work

Thank you for your help If you have further comments on the topics raised, please add them on a separate sheet.. Please leave the questionnaire in a prominent place, and it will be collected later today.

APPENDIX D1

PART A: Respondent's Background

1. Name : ______________________________
2. Designation : ______________________________
3. Department : ______________________________

PART B: Information related to the application of energy-efficient design in office building

1. What are the differences between energy-efficient building design and conventional building design?

____
____
____
____
____

2. What are the energy efficiency (EE) components applied in the EE building?

____
____
____
____
____
____

3. How do the building **maximize the energy efficiency**?

____
____
____
____
____

APPENDIX E1

PART A: Respondent's Background

1. Name : ______________________________
2. Designation : ______________________________
3. Department : ______________________________

1. What are the orientation and shape for the building? Why?

____

____

____

____

2. What is the approach had been taken in order to reduce the thermal effect in the building (Building envelope)?

(i) Wall systems

(ii) Window selection

(iii) Roof selection

(iv) Floor selection

(v) Others

____

____

____

______________________________-

3. How to maximize the daylighting usage in the building in term of architectural design?

(i) Window design

(ii) Shading

(iii) Others

____

____

____

APPENDIX E2

4. (a) What is the passive ventilation system used in the building?

(i) Wind cowl/windcatcher

(ii) Passive cooling approach

(iii) Others

(b) What is the active ventilation system used in the building?

5. What types of solar thermal collector used in the building? Which part of the building is suitable to install the PV system and why?

6. What types of rain water harvesting system used in the building? Passive or Mechanical (active)?

APPENDIX F1

PART A: Respondent's Background

1. Name : ____________________
2. Designation : ____________________
3. Department : ____________________

PART B: Information related to energy efficiency and renewable energy components in energy-efficient building

1. What are the main ***energy efficiency and renewable energy components*** applied in energy-efficient building? (*Briefly stated the components*)

APPENDIX F2

2. In your opinion, what is the ***other approach*** that can ***improve the energy efficiency in the building***?

APPENDIX G

Definitions

Questionnaire:
The work produced by the Licensor

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Period :
One year

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Further details :

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Malaysian Green Technology Corporation
No 2, Jalan 9/10,
43650 Bandar Baru Bangi,
Selangor Darul Bangi.

(Energy Commission)
Suruhanjaya Tenaga,
No 12, Jalan Tun Hussein,
Precinct 2,
62100 Putrajaya

Ministry of Energy, Green Technology and Water,
Block E4/5 Parcel E,
Federal Government Administrative Centre,
62668 Putrajaya

Invoices : If invoices apply they should be raised and paid to:
Building Use Studies Ltd.,
c/o Sprunt,
The Quadrangle,
180 Wardour Street,
London W1F 8FY
UK

Licence agreement

14/9/11

This is a questionnaire licence agreement between:

Adrian Leaman, Building Use Studies — *The Licensor*

and:

Ng Ban Huat, Department of Construction and Building Engineering, Universiti Tun Hussein Onn Malaysia — *The Licensee*

concerning the method/s:

BUS Methodology 2-page occupant questionnaire 2011 Workplace with Response version

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1. The licensor as beneficial owner grants the licensee rights throughout the territory for the period.
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3. The licensee undertakes that the following copyright notice is prominently displayed on all pages of the questionnaire and prominently in the report of survey, especially within data tables:

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More details are available of the approach on:
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Signed: Adrian Leaman

Digitally signed by Adrian Leaman
DN: cn=Adrian Leaman, o, ou,
email=adrianleaman@usablebuildings.co.uk, c=GB
Date: 2011.09.14 10:20:57 +01'00'

Adrian Leaman, Building Use Studies

Signed:

Ng Ban Huat, Department of Construction and Building Engineering,
Universiti Tun Hussein Onn Malaysia

VAT number: (GB) 371 1084 78 — Company number 1497266
Account Name: Building Use Studies Limited
Account No: 20207543
Bank Address: Barclays Bank, Barclays Business Centre, P O Box 32016, London NW1 2ZH
Bank Sort Code: 20-03-53 — Swift code: BARCGB22

APPENDIX H

Mr. Gregers Reimann
IEN Consultants Sdn. Bhd.
Syed Kechik Building , 8th floor
Jalan Kapas , Bangsar
59100 Kuala Lumpur, Malaysia.

Oct. 2012

Dear Mr. Gregers Reimann:

I am a master's degree by research student from Universiti Tun Hussein Malaysia (UTHM) currently doing a research titled: *Building Performance Analysis Model Using Post Occupancy Evaluation for Energy-efficient Building in Malaysia*. The aim of this research is to develop a survey framework for the identification of problems in respect to energy-efficient design which affecting occupants' comfort.

In order to achieve the objective of this research, the perspectives and opinions from the experts or peoples involved in the green building and built environment field are very much needed. Your involvements are important to **validate the contents of the questionnaire**. Hence, I sincerely hope that if you could take 10-15 minutes of your time to fill out the validation form in **APPENDIX A**. Your cooperation in this regard will be highly appreciated.

Enclosed with this letter:

(i) Letter of Permission from University

(ii) APPENDIX A: Validation Form

(iii) APPENDIX B: Questionnaire Survey Form

(iv) Reply letter: with self-addressed stamped envelope

Yours Sincerely,

(Ng Ban Huat) Matric no.: HF100107
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
Tel. no.: +60166048535
Email address: ngbanhuat@hotmail.com

Supervised by:

(Assoc. Prof. Dr. Zainal Abidin bin Akasah)
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
Tel. no.: +60197515395
Email address: zainal59@uthm.edu.my

UTHM Universiti Tun Hussein Onn Malaysia
DR. HJ. ZAINAL ABIDIN B. HJ. AKASAH
Head
Department of Building and Construction Engineering
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor Darul Ta'zim
MALAYSIA

APPENDIX I

UNIVERSITI
TUN HUSSEIN ONN
MALAYSIA

FAKULTI KEJURUTERAAN AWAM DAN
ALAM SEKITAR
Tel : 07-4537302 / 7309 Faks : 07-4536070

UTHM/FKAAS/600-3/6/5 Jld. 2 (107)

16 Oktober 2012

TO WHOM IT MAY CONCERN

Sir/Madam,

QUESTIONAIRE SURVEY OF MASTER STUDENT OF FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING, UNIVERSITI TUN HUSSEIN ONN MALAYSIA

With regardsto above matter.

2. Kindly be informed that above named is currently a master candidate of Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia.

No.	Name	I/D / Passport No.	Matrics No.
1.	Ng Ban Huat	617972	HF 110184

3. Their master research is entitled **'Building Performance Analysis Model Using Post Occupancy Evaluation For Energy-Efficient Building In Malaysia'** under supervised of Associate Professor Dr. Zainal Abidin bin Akasah. Therefore, it would be much appreciated if you and your department could help the candidate in his questionare survey. Nevertheless, you and your department have the rights to act upon the request of the candidate.

Your kind co-operations are much appreciated.

Thank you,

"WITH WISDOM WE EXPLORE"

ASSOC. PROF. DR. HJ. ISMAIL BIN ABDUL RAHMAN
Deputy Dean (Research and Development)
Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia
✆ 074564202
Faxs : 017-4536588
E-mail : ismailar@uthm.edu.my

IAR/adi/projek sarjana

APPENDIX J

Universiti Tun Hussein Onn Malaysia

86400 Parit Raja, Batu Pahat, Johor Darul Ta'zim. http://www.uthm.edu.my

Fakulti Kejuruteraan Awam
Dan Alam Sekitar
Tel. : (6)07- 453 7308 / 7306 / 7309
Faks. : (6)07- 453 6070

Rujukan Kami (Our Ref.) :
Rujukan Tuan (Your Ref.) : UTHM/FKAAS/600-12/4 Jld 10 (31)
Tarikh 19 May 2011

KEPADA SESIAPA YANG BERKENAAN

Tuan,

MEMOHON KEBENARAN UNTUK MENDAPATKAN MAKLUMAT PROJEK PELAJAR SARJANA

Dengan segala hormatnya saya diarah merujuk kepada perkara di atas.

2. Adalah dimaklumkan bahawa penama di bawah adalah pelajar sepenuh masa kursus Sarjana Kejuruteraan Awam di Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor.

BIL.	NAMA	NO. K/P	NO. MATRIK
1.	Ng Ban Huat	871209-04-5319	HF 100107

3. Mengikut keperluan kursus, pelajar tersebut dikehendaki menyiapkan projek yang bertajuk ***'Building Performance Analysis Model Using Post Occupancy Evaluation For Energy – Efficient Building In Malaysia',*** di bawah penyeliaan Prof. Madya Dr. Hj. Zainal Abidin Bin Akasah.

4. Pihak Jabatan ingin memohon kerjasama dan bantuan pihak tuan memberikan sebarang maklumat yang dijangkakan bermanfaat kepada pelajar berkenaan demi untuk menjayakan tugasnya. Selain daripada itu, kami berharap agar pelajar tersebut dibenarkan masuk ke kawasan terlibat bagi tujuan membuat kajian dan mengambil gambar *(sekiranya perlu)* selain daripada mematuhi arahan peraturan yang sediada di tempat tuan.

Segala kerjasama yang diberikan amatlah dihargai, terima kasih.

'DENGAN HIKMAH KITA MENEROKA'

Yang benar,

DR. ZAWAWI BIN DAUD
Timbalan Dekan (Penyelidikan dan Pembangunan)
Fakulti Kejuruteraan Awam dan Alam Sekitar
Universiti Tun Hussein Onn Malaysia
✆ 07-4537304

VITA

The author pursued his degree at the Universiti Tun Hussein Onn Malaysia and graduated with the Bachelor of Construction Management with Honours in 2011. Upon graduation, he continued his Master's Degree (by research) at his alma mater under the Faculty of Civil and Environmental Engineering. Throughout his research, He had published over 7 conference papers and journals. His research work is mainly about energy-efficient building and built environment. In 2012, the author had received best paper awards in MiCRA conference with the research title: Post Occupancy Evaluation: A Newly Designed Building Performance Survey Framework for Energy-Efficient Building.